POWER PLANT ENGINEERING

GENERATION, TRANSMISSION AND UTILIZATION OF STEAM, ELECTRIC, DIESEL AND HYDRAULIC POWER

Contents

Boilers—Past, Present and Future	2
Why Modern Boilers?	3
Boiler Development from Perkins to Twin Branch	10
Features of Modern Steam Generators	16
Fuels Need Room to Burn	22
Much Fire but No Smoke, Please!	26
Economizers and Air Preheaters Turn Waste into Profit	32
No Watered Stock Here	35
Desuperheating—An Integral Part of the Modern Plant	38
On the Way Out	41
Steam Dryers and Purifiers	44
Boiler Operation	47
Boiler Control	52
Steam Temperature Regulation	55
Feedwater Regulation	59
Evolution of the Modern Boiler Unit	60
Feedwater Treatment and Control	69
Unorthodox Boilers	72
Mercury Vapor Boilers	74
Small, High Capacity, High Pressure Boilers	77
European Boiler Developments	80
Montville Sets a New Record	85
A.S.M.E. Holds 58th Annual Meeting	87
X-Ray Examination of Castings	89
New Equipment	90
News from the Field	93
For the Engineers' Library	94
Power Plant Construction News	96

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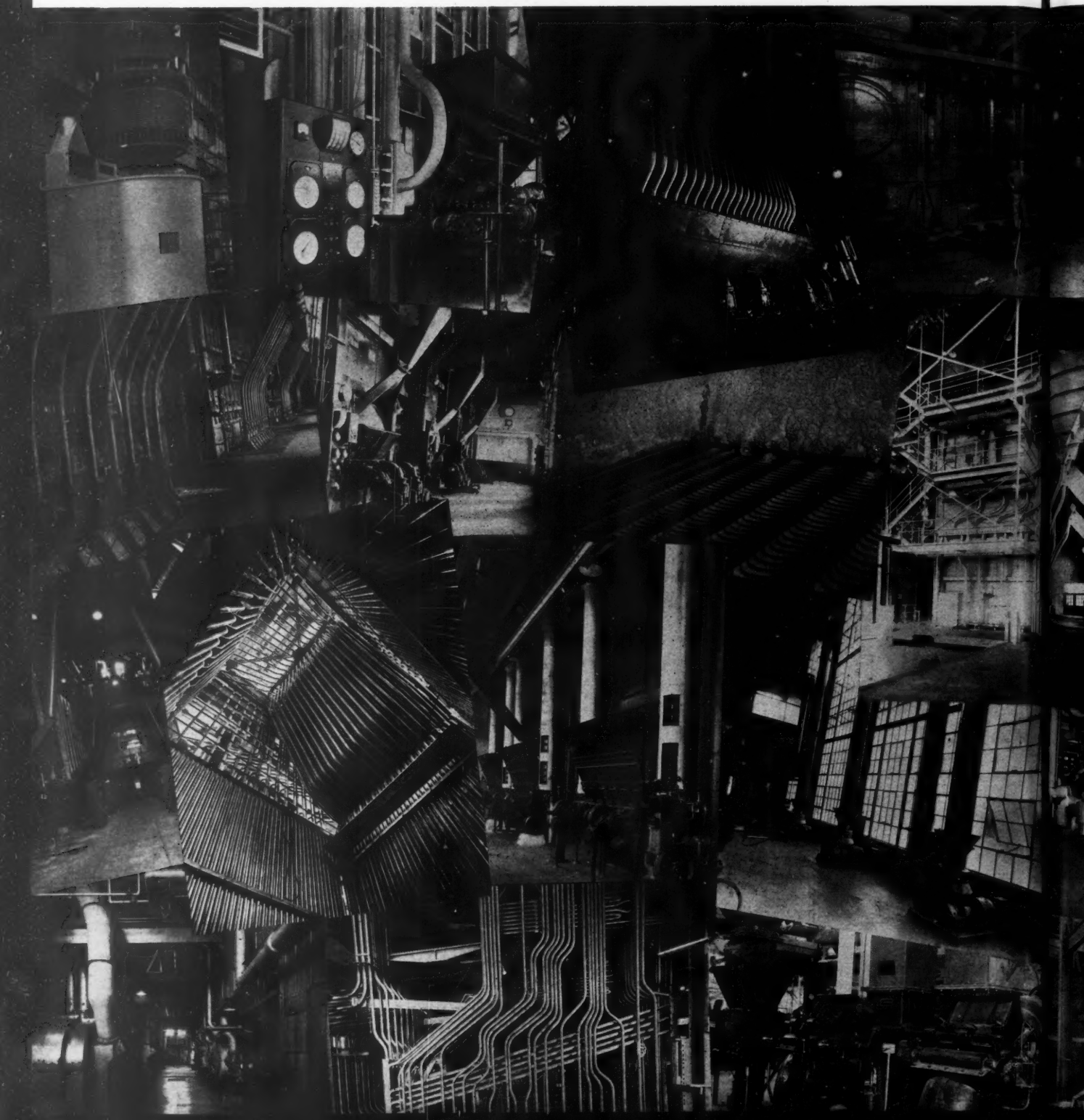
BOILERS — Past, P



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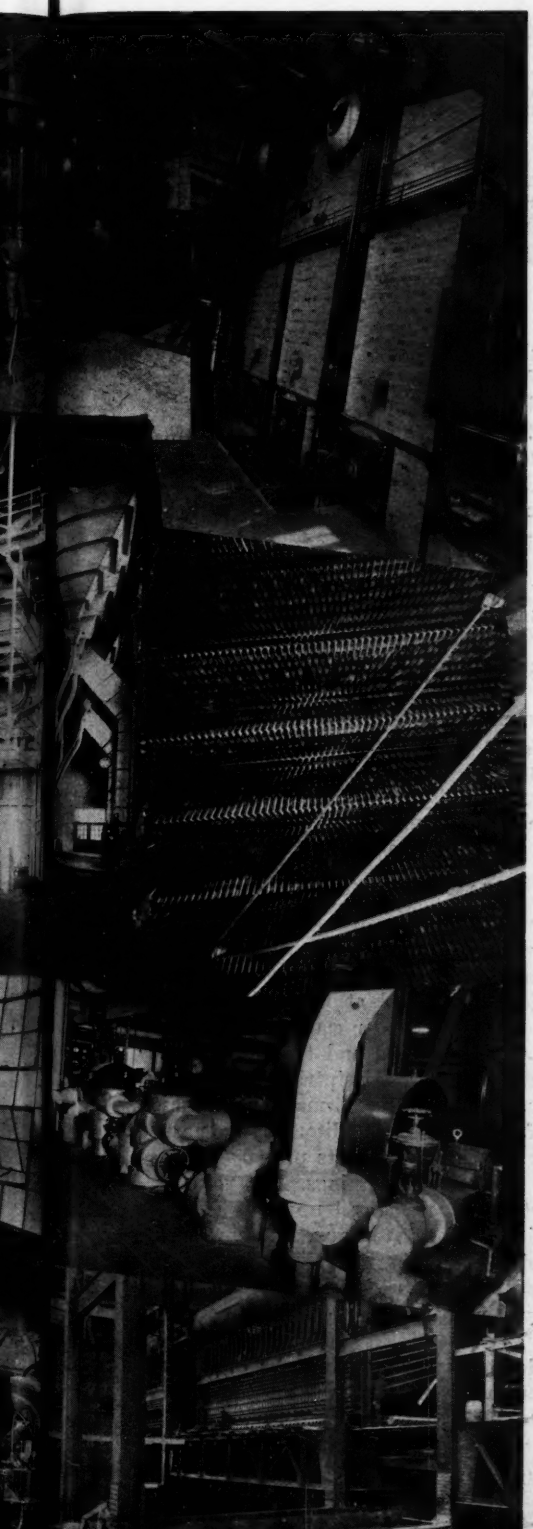
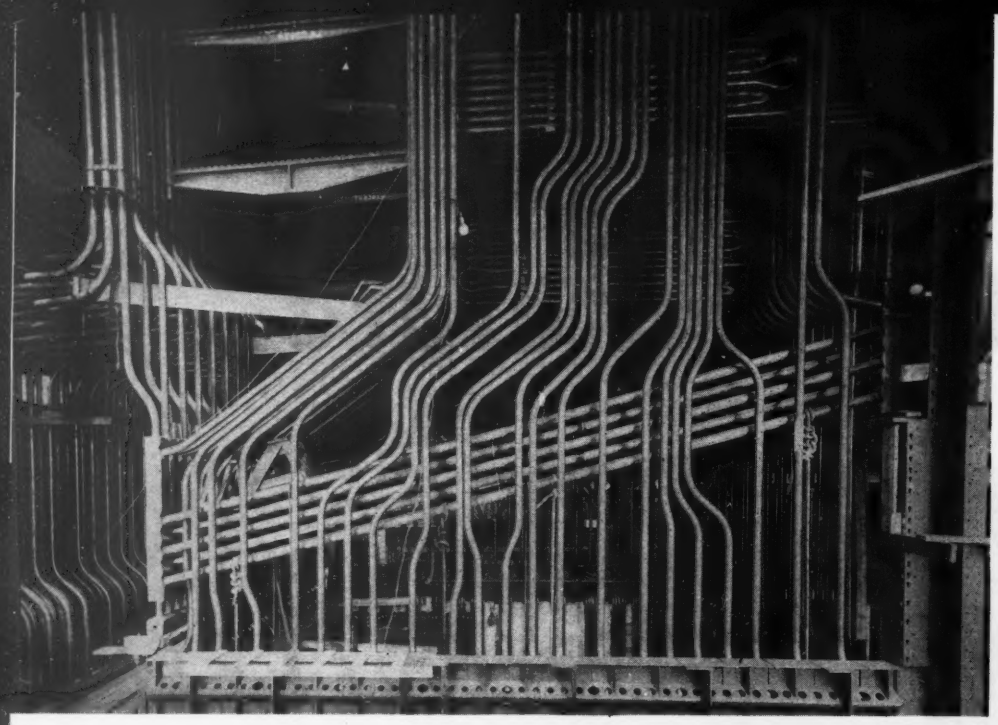


IN WRITING an introduction to a specialized issue such as this, it is always difficult to avoid saying things that have not been said in the pages that follow. For, as is true of most introductions, to books or articles or papers, these lines are being written last, after all other material is finished and, as the printers say, the issue "put to bed." To be quite frank, what we say here is being written largely to fill up the space alongside this random group of photographs—a montage in technical parlance. This itself is shown more for its pictorial effect than to convey information. Those familiar with boiler practice will find in it old and new types of boilers, some of which they may be familiar with, others not. You will find examples of the "fearsome" modern units referred to in the first article as well as old hand fired boilers of a bygone age. Again you will find in it special types of boilers, mercury boilers for example which belong, if they do belong, to a future age. All of them together literally as well as figuratively, present a picture of the boiler art in its present state of development. ¶ It would be presumptuous, however, to assume that this picture possesses any semblance of permanence. There would be something wrong with it if it did. In one of the articles further back in this issue we quote from a statement made by Andrew Carnegie in 1905 concerning the state of automobile development at that time. Only in the light of modern automobile development do we realize how limited Carnegie's viewpoint was, and while this in itself is of no consequence we can profit from the knowledge by not permitting ourselves to think of modern boiler development in the same limited sense. ¶ Successful and highly developed as modern boilers are, they are possessed of much complexity that could well be disposed of. Fundamentally, the simplest boiler is a single tube with water going in at one end just as fast as the steam leaving it at the other. This idea was used in some of the early steam automobile boilers but more recently it has been applied to large stationary boilers. Whether such schemes point the way to the pattern of boilers that will be used in the future cannot be known now, but such new ideas should be given all the support we can give them. ¶ Up to the present our boilers have been the result largely of evolution—of invention mothered by necessity. But many things we use today—the products of fundamental research—arose from no recognized need nor possible public demand, they are the unanticipated results of scientific curiosity. There may be no distinct need for new methods of steam generation at the present time but this does not imply that better methods cannot be developed. The greatest danger to the further development of any field of human endeavor is our inability to throw off traditional patterns of thinking. We must not permit this limitation of the human mind to beset so important an art as that of steam generation.



WHY,

Construction view of high pressure boiler at Northeast station, Kansas City, Mo. Photo, courtesy Combustion Engineering Co., Inc.

WHEN JAMES WATT sat in front of the mythical teakettle and conceived the idea of utilizing the power of steam he had, in the parlance of present day radio comedians, "something there." He started something—something so vast, so tremendous in its import on the human race that could poor Watt have foreseen the full consequences of his discovery he might well have put the lid back on his kettle, made himself a cup of tea and let it go at that. For the forces which he set free when he confined the force of steam, though they affected every person in the civilized and uncivilized world, have made a rather complicated mess of what was once a simple place to live and Watt might have been appalled at the prospect of releasing so dangerous a force in a world of beings not particularly noted for their cultivation of the intellectual virtues.

This, however, is beside the point, the fact remains that Watt, though he may have made his tea, did not let the matter go, and built himself a steam engine. If he had not done it, someone else would have done so. As a matter of fact, others had had the idea before him—had built boilers and engines. Our historical books are full of quaint little pictures of cherubs grouped around Branca's turbine and before Branca, there was Hero and before Hero probably the Chinese had an engine—they had about everything else.

The origin of the idea of using steam power is lost in antiquity. It was certainly before history had begun to record any other than political events and before any invention, before any useful art had become a matter of notice among historians. In Hero's engine, described by Hero the Younger and dated about 120 B.C., we find the first record of the early history of the steam engine and it is a sad commentary on the intelligence of the human race and the progress of civilization that from the time of Hero we find no evidence of the useful application of steam for many hundreds of years. Here and there in special treatises we find that knowledge of the force of steam was not forgotten. Porta, De Cause and Branca in the period between 1600 and 1629 suggested crude schemes for utilizing the power of steam but it was not until 1663 that Edward Somerset, second Marquis of Worcester, actually built a steam engine. Then came Sir Samuel Moreland, Papin, Savory, Newcomen and finally James Watt. Whether he ever sat in front of a teakettle is not known, the chances are he didn't, but it is popular history and people are taught to believe it just as they are the story of George Washington and the cherry tree.

What actually happened was that a model of a Newcomen engine was given to Watt for repair and he, being an ingenious young man, soon became aware of its numerous deficiencies and this led him to devise a better one.

The rest is common history. From that time on the power of steam was in the ascendency and as a result of continued development, today we find the world filled with boilers and engines of such size and complexity and cost that if poor old Watt could come back today and see them he would not believe his eyes.

The Modern Boiler

For the modern boiler is a fearsome thing—something which must have its origin in some diabolical scheme to confound the human race in its efforts towards greater power. Take a good look at one of these modern units, preferably when it is under construction, look at the hundreds of tubes, twisting and turning upwards, downward, side-ways and across in intricate patterns, at the drums and baffles disposed in all manner of fashion. Contemplate the furnace with its auditorium-like proportions, its water walls, slag screens, its primary and secondary divisions, its refractory linings. Tilt your head backward and let your gaze travel upwards along its Empire State height and try to figure out how such a contraption could possibly have evolved from James Watt's first wagon boiler. As the farmer said when he saw a kangaroo, you may conclude that "there ain't no such animal."

Why are modern boilers what they are? How is it that such a fundamentally simple process as the evapora-

MODERN BOILERS?

Why is it that such a fundamentally simple process as evaporation of water has resulted in the fearsome systems of tubes, drums, air heaters, and other things we call the modern boiler? Why the enormous pressures and the high temperatures? What is the reason for the huge furnace with its complicated water walls? While many of these questions are involved they can be answered and it is the purpose of this article and the others that follow in this issue to discuss them in the light of modern knowledge

tion of water into steam should have resulted in the development of these complex systems of drums and tubes? Why the enormous pressures—600, 1200, 2400, even 3200 lb. per sq. in. and why such high temperatures —temperatures as high as 1000 deg. F.? What is the reason for the huge furnaces and their varied and complicated construction? Why all the associated equipment —air heaters, economizers, fans, costly precipitators and why such things as superheaters and in some cases, reheaters? Why so many tubes and why does their arrangement vary, why the complicated systems of headers and drums and water walls, slag screens and a thousand other things that make the modern steam boiler at once the joy and the despair of those that design and operate them? What is there about the process of evaporating water that demands all this complexity?

It is the purpose of this article and the other articles that follow in this issue to answer these questions. Much has been written about boilers and boiler technique and everything we say about them in these articles probably has been said somewhere else before, but the material is scattered and not always convenient of access. Our purpose here is to collect and arrange in a single issue the essential information on steam generator practice in its most modern aspects and to describe the evolutionary processes by which boiler technique has reached its present high state of development.

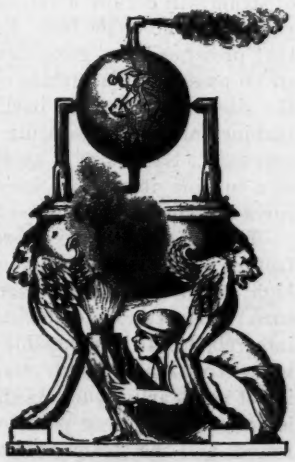
At the beginning of course is the load—the ever growing demand for power shown most tangibly by the electric load curve which during the past decade has been rising at an accelerated rate. This increasing demand for power made it desirable to take advantage of every possible increment in the efficiency of our generating equipment. Whereas a difference in efficiency of a few per cent in the case of a small generating unit makes comparatively little difference in the total cost of operation, the same percentage in the case of a large unit accounts for the savings or loss of many thousands of dollars annually. This called for higher pressures and temperatures in boiler operation.

The need for higher pressures and temperatures has existed ever since Watt's time but it was not until metallurgical developments, increasing loads and high fuel prices combined to make high pressure developments commercially desirable.

Why High Pressures and Temperatures?

The reason why high pressures and temperatures are desirable is shown by Fig. 2. For every pound of steam through the prime mover there is a condenser loss which can be considered approximately constant at 950 B.t.u. If the heat extracted by the prime mover can be raised from 250 to 500 B.t.u. per lb. the thermal efficiency would be increased from $250 \div (250+950) = 20.9$ per cent, to $500 \div (500+950) = 34.5$ per cent. For straight power generation high temperature is more important due to the necessity for keeping moisture at the turbine exhaust within 10 to 12 per cent. Where steam is needed at definite pressures more than a few degrees of superheat is usually superfluous. With exhaust conditions fixed in this way, by-product power generation in usable quantities requires higher pressures rather than higher temperatures.

While the advantages of going to higher temperatures rather than higher pressures are obvious enough from a purely thermodynamic standpoint, many difficulties are encountered when attempts are made to put them into practical use. The present temperature limits are fixed entirely by metallurgical considerations and the use of still higher temperatures is dependent upon the re-



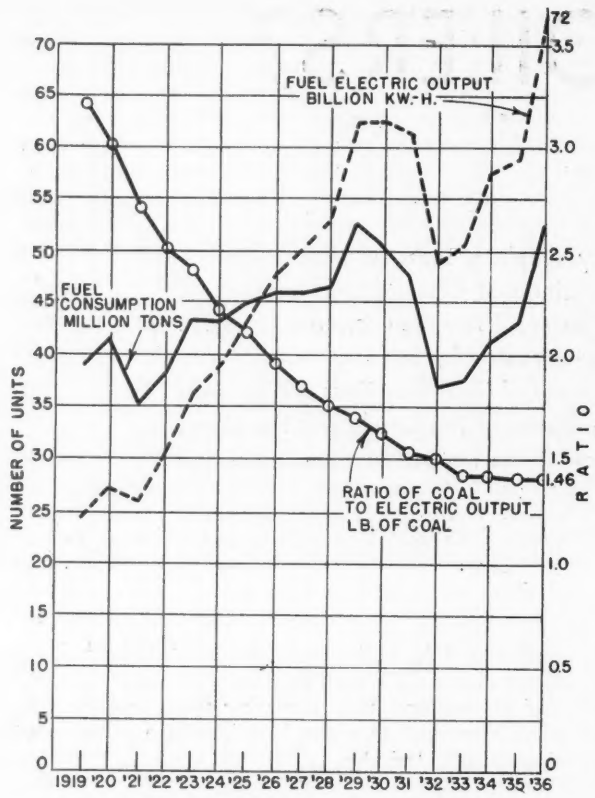


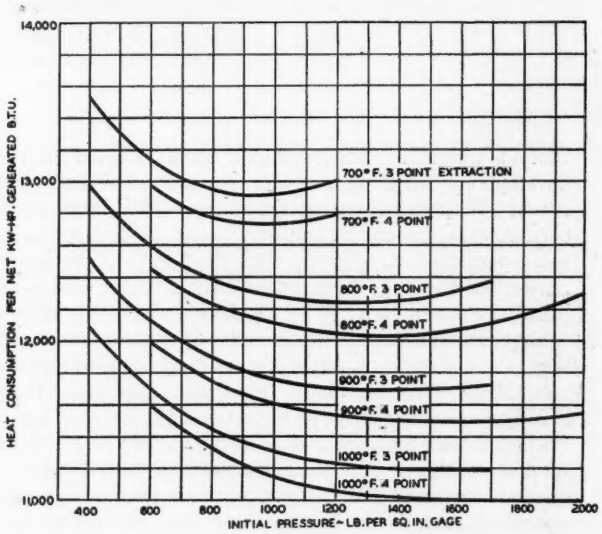
Fig. 1. At the beginning of all boiler development is the load—the ever growing electrical load. This chart shows the Public Utility fuel electric output compared with the fuel consumption. The amount of fuel used per kilowatt-hour output, it will be noted, has steadily decreased

searches of the metallurgist, upon the development of steel alloys capable of withstanding these higher temperatures and pressures.

Aside from the thermal economy of high pressures, the question of pressure is equally important in that it has a definite bearing on the size of the equipment used, particularly the turbine. This is true because steam is an elastic medium, expanding with a decrease in pressure. As shown by the accompanying table one pound of steam at an absolute pressure of 2000 lb. per sq. in. occupies a space of less than 2/10 of a cubic foot, whereas at a pressure of 200 lb. per sq. in., this same pound of steam will occupy a volume of 2.3 cu. ft. and at 20 lb. per sq. in., 20 cubic feet. From this it is quite obvious that pressure has a great deal to do with the size of the steam passages in a turbine or engine and therefore with the size of the turbine itself. In Fig. 3 is shown how turbines of the same rating vary in size with different pressures. Since size is an important factor in the cost of a turbine, it becomes desirable to employ steam pressures as high as possible.

Thus, then, we have the reasons for the two principal factors which characterize modern boiler practice, first, high steam temperature and second, high steam pressure. These two characteristics of steam, are, of course, interrelated. It is impossible to have high steam pressure without reasonably high temperature though the reverse is not necessarily true. As the pressure in a steam boiler is raised, the boiling point of the water in the boiler is raised, and the steam produced automatically takes the temperature corresponding to the pressure existing at any time. The temperature of the steam for any pressure can be found from the steam tables. Thus, while the temperature of steam at atmospheric pressure is 212 deg. F., at a pressure of 1000 lb. absolute, the temperature is 545 deg. F.

The demand for high capacity, high pressure boilers necessitated a change in furnace practice from that which prevailed in the early years of steam boiler development. As long as a comparatively small amount of heat was involved simple refractory lined furnaces of moderate proportions, operating under natural draft, were quite adequate, but as the demand for heat required by large boilers increased, it was found that the existing types of furnaces were no longer adequate. The heat release necessary first demanded furnaces of larger proportions and next a modification in design. With the higher temperatures involved, refractory furnace walls were no longer feasible since the refractories melted and so water cooled


700° F. 3 POINT EXTRACTION
700° F. 4 POINT
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900° F. 4 POINT
1000° F. 3 POINT
1000° F. 4 POINT
HEAT CONSUMPTION PER NET KW-HR. GENERATED B.T.U.
INITIAL PRESSURE~LB. PER SQ. IN. GAGE

Fig. 2. Effect of pressure and temperature changes on station heat consumption for straight regenerative cycle with three and four point extraction

walls were developed. At the same time the furnace volume increased enormously and with it the heat liberation per cubic foot of volume, although more recently as furnaces became very large the heat release per cu. ft. decreased somewhat. Present practice runs from 20,000 to 40,000 B.t.u. per cubic foot of furnace volume per hour, but some furnaces in regular use are designed for heat liberations up to 90,000 B.t.u. per cu. ft. per hr. and with certain special types of steam generators, the Steamotive, for example, heat liberations as high as 400,000 B.t.u. per cu. ft. per hr. are attained. In the Velox boilers a heat release of over 300,000 B.t.u. per cu. ft. per hr. is attained.

The necessity for high heat release and the combustion of increasingly greater amounts of fuel, naturally called for changes in draft practice. Long before the advent of water cooled walls, the use of forced and induced draft fans was common practice, but with the increasing use of large water cooled furnaces, the draft question became of increasing importance, since it was essential to move the large quantities of gas involved at rapid rates. The high heat releases necessary in the fur-

nace called for pre-heating of the air supplied for combustion and for changes in firing practice. Since 1920 pulverized coal firing had come into use, first in the form of central systems, but this was superseded by the unit system in almost universal use today. Under stimulus of competition from pulverized fuel systems, stoker technique developed to a point undreamed of by even the most ambitious designers, two decades ago. Today, we have not only water cooled furnaces but water cooled stokers as well.

Now it is natural to ask, are all these things necessary? Granting that high pressures, high capacities and the consequent high heat release is necessary, cannot the ultimate result be obtained in a simpler way? Why are all these accessories, air heaters, economizers, superheaters, etc., necessary? The old Scotch marine boiler had water cooled furnaces and its performance was very good, high efficiencies were obtained with them. Why can't we just make a Scotch marine boiler larger?

The answer to this question is that the Scotch marine as well as the return tubular and other similar type boilers have size, pressure and efficiency limitations which rule it out of the high pressure field.

To begin with, it would be economically impossible to build a boiler of the Scotch marine type in large capacities for pressures of 1200 lb., nor could they be provided with sufficient heating surface. There is also a limit to the efficiency because it is obviously impossible to cool the gases lower than the saturated steam temperature. As a matter of fact, the temperature difference between the outgoing gases and the steam temperature in

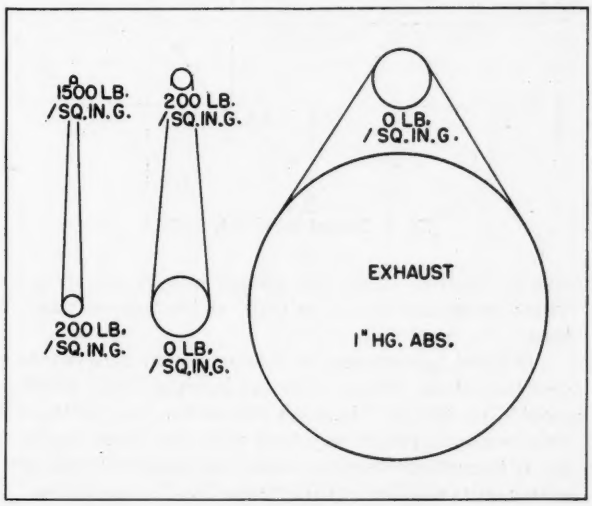


Fig. 3. Diagram showing how turbines of the same rating vary in size with different pressures

such boilers is often 100 to 150 deg. F. which, for 150 lb. pressure steam would mean a gas temperature of 450 to 500 deg. F. At higher capacities this differential increases, giving a typical efficiency curve as shown by Fig. 4.

As long as pressures were low and operators of boiler equipment were satisfied with what was known as 100 per cent rating, the simple Scotch or h.r.t. boiler worked very well. The fact that the point of maximum efficiency of the small boiler is at 100 per cent as shown in Fig. 3 is not mere coincidence, but is due to the fact that in the early days the boiler horsepower was arbitrarily related to the amount of steam produced by about 10 sq. ft. of heating surface at maximum efficiency.

As combustion equipment was improved, however, the temptation to cut investment costs by pushing the boilers harder could not be resisted, but as ratings went up the exit gas losses became higher. So somebody conceived the idea of putting a feed water heater in the exit gas passage to reduce the flue losses. This developed into the modern economizer which is much cheaper than boiler surface and, as it can be made counter current, the flue gases can be cooled almost to the temperature of the incoming feedwater.

The economizer proved very useful until the introduction of the regenerative cycle with extraction feedwater heaters. Then it was found better to heat the feedwater with heat salvaged from the condenser than to save it from the flue gases. So the economizer was out of a job. The heat in the flue gases could not be thrown away, however, so air heaters were developed and these proved very useful with pulverized coal which was being developed about the same time. With preheated air, and turbulent burners, however, the heat releases which resulted were damaging to refractory walls so air cooled and later water cooled walls were brought in.

The use of water cooled walls proved so desirable that today half of the total steam produced by the unit may come from the water walls. Experience also showed that there was a considerable economic temperature differential between the maximum extraction temperature and the saturated drum temperature. Contrary to earlier opinions that economizers did not fit into the picture with feedwater temperatures much in excess of 212 deg. F. it was found that economizers fit into the scheme very

Table—Specific Volume of Steam at Various Pressures

PRESSURE in #/SQ." ABS.	SPECIFIC VOLUME IN CU. FT./LB. WITH A SUPERHEAT OF 0 DEG. F.	200 DEG F.
0.5	641	880
1	334	453
2	173	234
10	38	50
20	20	28
100	4.4	5.8
200	2.3	3.0
1000	0.4	0.6
2000	0.2	0.3

nicely when taking water from the high pressure extraction heater and heating it to the steaming point.

So the economizer came back into the picture, this time as a steaming economizer. Thus, the modern boiler

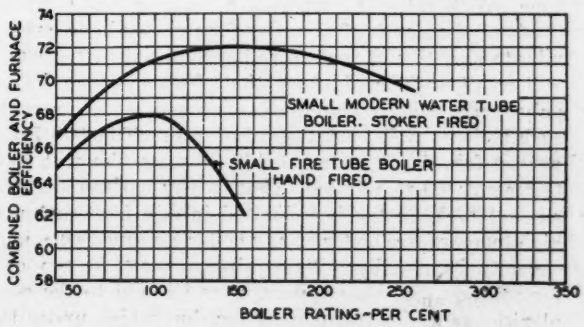
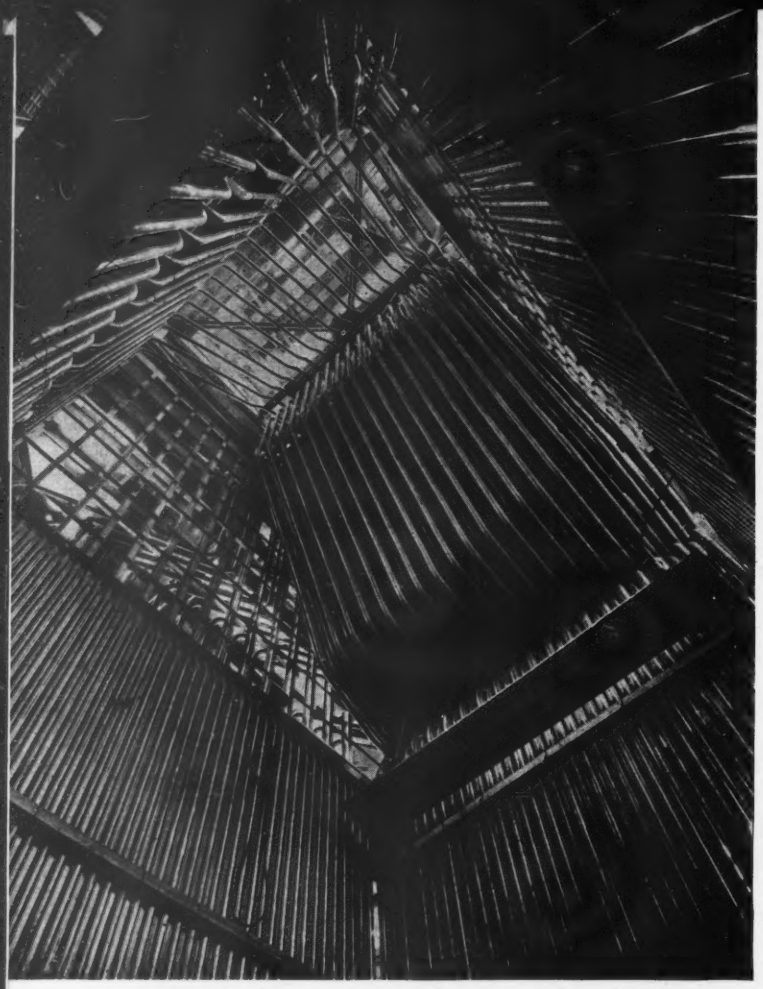


Fig. 4. Typical efficiency curves of simple boilers



has both economizer and air heater as well as water walls and superheaters.

These, then, are the reasons why the modern boiler is a complicated affair and in this way the general design of the modern steam generator is arrived at.

One requirement imposes another. Many conditions become of increasing importance as the size of the units increase. The high steaming rates, for example, impose the feed water problem—the difficult task of providing hundreds of thousands of pounds of clean, pure water per hour, free from scale forming impurities and with no corrosive properties. As a consequence, elaborate systems of feed-water treatment and concentration control have been developed. In a boiler evaporating a few thousand pounds of steam per hour a small amount of scale forming impurities in the water, although never desirable, is not a serious matter since the accumulation of a deposit on the heating surfaces takes a relatively long time. With rates of evaporation running into the hundreds of thousands of pounds of water per hour, even a minute quantity of scale forming material in the water will result in the rapid formation of scale deposit, hence, only water that is absolutely pure can be tolerated in such boilers. At a heat absorption rate of 100,000 B.t.u. per sq. ft. per hr. a mere 1/100 in. scale film will raise the metal 100 to 400 deg. That is why not the slightest amount of scale can be tolerated in any high pressure, high temperature boiler or any boiler equipped with high capacity water walls. This requirement calls for evaporators, filters and other apparatus which add to the complexities of boiler plant operation, but which under the circumstances cannot be dispensed with.

If high rates of evaporation have complicated the feed water problem, the high rates of combustion have made the problem of ash removal one of major importance, resulting in the development of dry and wet bottom furnaces, slag screens, sluicing systems, slag tapping arrangements, and at the other end of the gas passage, of fly ash removal equipment. It would be interesting if we could get James Watt's reaction, if he could come back today and see the molten ash being tapped from a modern furnace, or to regard his consternation at the spectacle of a Cottrell electrostatic precipitator in action on top of a modern boiler plant.

These things, precipitators, ash sluicing systems, etc., are costly and considered unproductive, but in view of present conditions and requirements are necessary. Any plant designer would willingly avoid spending anywhere from $20,000 to $100,000 or more for an electrostatic precipitator or other elaborate dust removal apparatus if he could do so, but with plants located as they are, in or close to cities or residential areas, he has no alternative but to put them in. If he does not put them in, public opinion will be aroused and before long ordinances

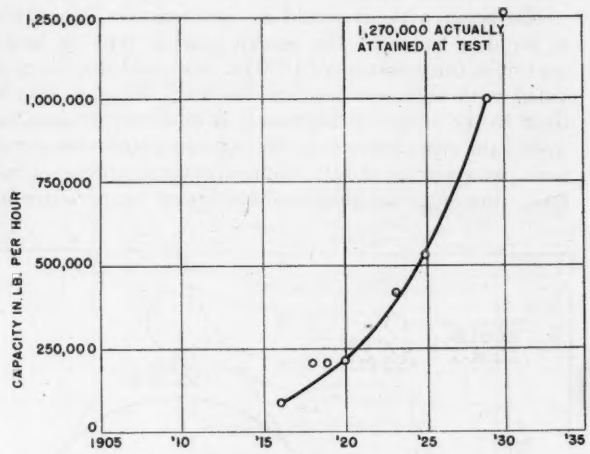


Fig. 5. Sizes of boiler units available

will be drafted which will compel him to put them in, These things are necessary evils, at the present time, at least.

It is not our purpose in this particular article to discuss the details of these various phases of boiler development since this will be done in articles that follow, but we cite them to show why they were developed and how all of them taken together make the modern steam generator quite a different thing from the old time boiler.

The old time boiler was largely a vessel filled with water. To increase the heating surface tubes were introduced quite early in the history of boiler development, but for a long time it remained essentially a vessel filled with water. Containing a considerable quantity of water as compared to its steaming capacity, such boilers had considerable storage capacity.

Today the boiler itself has all but disappeared—the drums have grown smaller and in the boiler proper only a few tubes remain. In its place are elaborate water cooled furnaces, economizers, air preheaters, superheaters, reheaters and automatic combustion control. What the present day steam generator lacks in storage capacity is compensated for by high steaming ability coupled

with completely automatic combustion and feed water control system. The whole unit is a delicately adjusted, highly complex system, instantly responsive to even the slightest variation in load and capable of efficient operation over a wide range of loads.

Thus far, we have been considering the more or less orthodox type of boiler—units using natural circulation of water and which were evolved naturally from the earliest types.

In other directions, however, radically new ideas are being put into practice. To increase the range of the thermal cycle and thereby to increase the economy of the plant as a whole, the mercury cycle has been developed and with it the mercury boiler.

The development of the mercury cycle was first carried on at Hartford and since then at Schenectady and Kearney. But more recently, two small mercury boilers, one using forced circulation and the other natural circulation, have been developed and placed in operation at the Pittsfield and Lynn works of the General Electric Co., and these show considerable promise. They are small, compact, efficient and are rated at about 1900 kw.

Another recent development of great importance is the so-called "Steamotive," which is a small, compact, highly efficient steam electric generating plant adaptable for either stationary or mobile applications. This uses a forced circulation type of boiler under completely automatic control, operating at high pressure and temperature. This development is of particular importance in that it provides a steam driven power source capable of competing with internal combustion engines in fields which the latter have had to themselves.

The announcement of this development came somewhat as a surprise to the engineering profession at the close of 1936, when the details were disclosed at the A. S. M. E. meeting in New York. Although rumors of the development had been prevalent from time to time, few of the details were known until the complete unit was described. Of course, it is easy to look back over a period of years to the locomobile, the series boiler, higher pressures and temperatures and metallurgical programs and show that this "Steamotive" development was a logical development arising in a perfectly definite evolutionary manner. Nevertheless, it was an outstanding piece of work by the three companies who cooperated in its development, and it shows what can be accomplished by intelligent cooperative effort. Although developed for comparatively small steam outputs at present, it is perhaps indicative of future furnace construction for larger boilers, all metal furnaces, positive furnace pressures and completely coordinated auxiliaries all under automatic control.

In Europe, totally new types of boilers have been invented, boilers not evolved from earlier models but based on entirely new ideas. These boilers, or more properly steam generators, are represented by the Benson, Loeffler, Velox, Atmos, Schmidt-Hartmann and similar types. Such units incorporate features as forced water circulation and indirect evaporation and in some cases, combustion under pressure.

Whether these new units point the way to the pattern of boilers which will be used in the future, or whether the present day American types will survive, it is impossible to say, but all of them today represent boiler development. Perhaps the whole situation is too complex; perhaps the whole business of evaporating water at high pressures and high temperatures in large quantities can be solved in a much simpler and more fundamental manner, but until such methods are found we will be forced to endure and master the complexities which beset the art. Perhaps the most encouraging part of present day development is that scarcely two boilers installed today are alike. Though some may deplore this lack of standardization, this condition points to a healthy state of flux where almost anything is more than likely to happen.

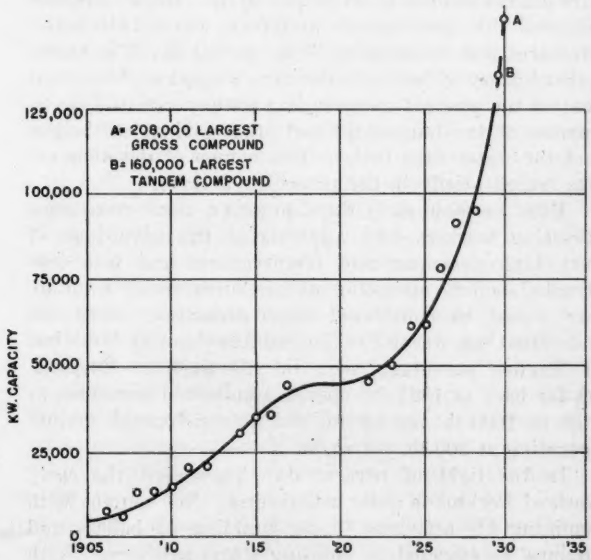


Fig. 6. Sizes of turbine units available

Fig. 3. The use of high temperature in boiler operation depends upon advances in the field of metallurgy. This picture shows a technician making a creep test reading in the research laboratory of the U. S. Steel Corp. Gradually accumulating knowledge regarding creep will have an important bearing on future boiler design

Boiler Development From

Jacob Perkins

IN THESE Days of 1200 and 1400 lb. pressure boilers not to mention the recent announcement of the selection of 2500 lb. for Twin Branch Station it may seem strange that so few know of Jacob Perkins who pioneered in high pressures. Yet over 100 years ago Perkins operated boilers at 800, 1200 and even 1600 lb. pressure. As shown in this discussion, however, Jacob Perkins was ahead of his time. Many problems had to be solved before Perkins' ideas could be successfully applied.

IN THE PRECEDING ARTICLE we discussed briefly the factors which led to the development of present day high pressure, high temperature and high capacity steam generators. But we did not explain *how* it was done.

In the light of present day knowledge the history of the course of boiler development appears quite logical but the way to modern 1200 lb. boilers was beset by many difficulties, some of them real, others mental. To surmount the latter was perhaps the most difficult. Early boiler development proceeded largely on a hit and miss basis and prejudices regarding certain practices were difficult to dislodge despite all logical argument to the contrary. Thus one large boiler manufacturer not so many years ago refused to build a boiler 14 tubes high as specified by a prospective customer, merely because it had never been done and because they did not believe in it. As a consequence they lost the order.

Even today, with all the accumulated knowledge regarding the principles of steam generation, the present average industrial steam pressure throughout the world probably does not exceed 120 lb. per sq. in. Utility power station practice makes a better showing with a pressure of 350 lb. average for the world but this is far from the pressures used in the high efficiency plants of the world.

In forming an opinion of the state of any art we are likely to be misled by the outstanding and spectacular examples of that art and this is particularly true of the art of boiler design. It is true, as was stated in the preceding article, there are many high pressure and superpressure installations now in operation within the range between 700 and 2100 lb. per sq. in. and with temperatures from 850 to 1000 deg. F., but these are not necessarily a measure of the state of the boiler art as a whole. An enormous saving in coal and other fuel is waiting to be effected throughout the world by raising the average steam pressure in stationary land practice, locomotives and steamships.

From the very beginning the outstanding problem in the development of steam power has been to construct boilers of sufficient size and pressure to give economical power generation. Because of the lack of such boilers, the high pressure Savery pumping engine in 1699 could not be made a commercial success whereas the Newcomen pumping engine came into widespread use largely because only 1 or 2 lb. per sq. in. pressure was necessary. For such service balloon or haystack boilers were easy to construct in large sizes. When the Watt condensing engine was developed, the wagon or tank boiler operating at 5 or 6 lb. pressure became the standard.

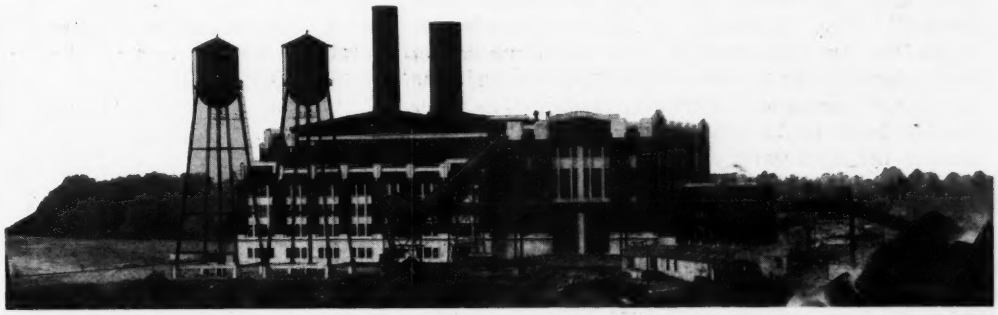
There were others in the field, notably Richard Treithick in Cornwall and Oliver Evans in the United States, who saw clearly that the future depended upon increasing the steam pressure and therefore reducing the size and weight of engine and boiler per unit-power output. During the period between 1780 and 1800 Trevithick invented the Cornish boiler cylindrical in shape with an internal furnace flue and was able to raise the steam pressure almost at once to 25 lb. per sq. in. Rapid advance followed this development and from about 1810 boiler pressures rose from 25 to 50 lb. per sq. in. The subsequent history of land practice is to a considerable extent that of the gradual increase in pressure with the development of the Lancashire and other cylindrical boilers and the water tube boiler. This course of development was traced briefly in the preceding article.

Even in these early days, however, there were some farseeing workers who appreciated the advantage of very high pressures and temperatures and who constructed boilers operating at pressures which even today would be considered super-pressures. Such an individual was Jacob Perkins, an American by birth but of English parentage, who did his work in England. As far back as 1827, he operated boilers at pressures as high as 1600 lb. per sq. in. and he constructed engines operating at 800 lb. per sq. in.

In the light of present day knowledge, the early work of Perkins is quite astonishing. Not content with confining his activities to the building of boilers and engines, he engaged in building steam artillery. With his boilers operating at pressures up to 1600 lb., he operated steam canons "throwing 60 balls of 4 lb. each in a minute with the correctness of a rifled musket and to a proportionate distance." With another gun, built for the French government, "balls were discharged at the rate of 500 to 1000 per minute, the steam blowing off at the escape valve the whole time."

That he had faith in the correctness of his own ideas

Perkins to Twin Branch



Twin Branch Station where a 2500 lb. boiler is to be installed

may be gathered from the following advertisement which appeared in a London paper in 1827:

"The high pressure safety steam engine. Perkins & Co. are now ready to receive orders for steam engines. They will guarantee the saving of at least one-half the fuel, three-fourths of the weight and three-fourths of the bulk and will charge but two-thirds of the price of the best London made condensing engine; reserving the right to one-third of the savings. Communications left at Perkins & Heath's, No. 69 Fleet St. will be attended to."

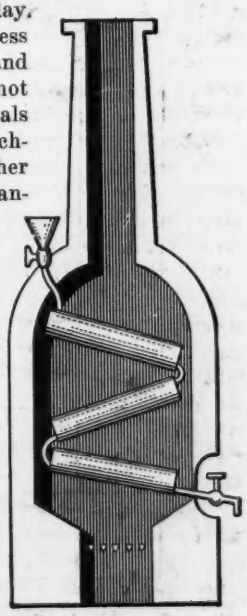
Thus it is seen that Jacob Perkins was not only a pioneer in high pressure technique but also in financing methods, since the payment out of savings implied in this advertisement is one used by a number of equipment manufacturers today.

It is not the purpose here to describe Perkins' work in detail but it is interesting to know that he knew as much about high pressure as he did and that under the tremendous handicaps which beset his work that he was able to actually produce boilers and engines that worked. He employed many ingenious designs for steam generators, including, for example, small copper vessels 3 in. thick and heavy narrow-bore tubes, made by boring out cast iron bars! Generally, Perkins adopted the principle of operating relatively small size generators kept filled with water and having a heavily loaded safety valve in the circuit. He used a powerful feed pump with what was practically forced circulation. He was, however, at least a century ahead of his time, and it is not surprising to know that he met with little sympathy or support.

But if Perkins' knowledge and work is surprising in the light of modern developments, there were other ideas on boilers and engines abroad in those early days which, even if they did not actually reach the tangible stage that Perkins' ideas did, nevertheless they are interesting. One of these concerned the mercury boiler. In the Journal of the Franklin Institute and the American Mechanics Magazine in July 1826 there was presented a proposal to built, as it was quaintly expressed, a "Quicksilver Vapour Engine." Apparently, this engine was never built but it embodied an idea which was put into practice only in recent years. "The bottom of the boiler," wrote the inventor of this early scheme, "is very small and strong and conical and the termination of the cone is in contact with the burning coals which surround it. Their heat is communicated almost instantaneously to the quicksilver in the boiler, throwing it into a vapour at the temperature of 650 deg. F."

The editor of the Journal of the Franklin Institute did not think very much of the idea and in his comments pointed out that at 650 deg. F. the quicksilver vapour boiler would be nearly red hot and that it would be a difficult matter to make such a device.

How significant these comments were can be testified to by Mr. Emmet and the others who have been engaged in the development of the mercury vapor cycle as carried on by the General Electric Co. during the past 25 years. And those who have experienced the grief and difficulties inherent in operating steam boilers and turbines at temperatures of 900 to 1000 deg. in recent years also can appreciate the prophetic accuracy of the editor's remarks about the difficulties of high temperature. It has taken practically a century of painstaking labor and research to bring these ideas to the workable stage in which we find them today.



The slow rate of progress towards higher pressures and higher temperatures was due not only to lack of proper materials but to lack of knowledge and technique of fabricating. Whether Perkins understood the advantages of high pressure and temperature operation from a thermodynamic standpoint is not known, nor does it matter for he was doomed to failure almost from the beginning because of lack of material, facilities and economic necessity. At a time when any concentration of power over a few horsepower was unique, it did not matter much whether the thermal economy of a steam plant was 5 per cent or 15 per cent; the important thing was to get any kind of a plant in operation.

The first boilers built were in reality steam kettles but the advantage of extending the heating surface by means of tubes was soon realized and John Blakey patented the first water tube boiler as early as 1766. The necessity for inducing water circulation was also realized early in the history of boiler development. Perkins' boiler, in 1822, had positive circulation, indeed it was of the type which today would be called a "once through" boiler. A number of cast iron bars having 1½ in. annular holes through them and connected at their outer ends by a series of bent pipes outside the furnace were arranged in tiers over the fire. The water was fed slowly to the upper tier by a force pump, and steam in the superheated state was discharged from the lower tiers into a chamber from which it was taken to the engine.

The first sectional water tube boiler with well defined circulation was built by Joseph Eve, in 1825, but early development of the water tube boiler was slow and for a long time the shell type boiler held dominance. The reason for this of course was in the difficulties involved in the construction of water tube boilers. High class engineering and workmanship was required for this type, whereas the plain cylindrical, shell type boiler, even with one or two flues, was easy to build.

In many ways the steam boiler supplied the driving force which brought about its own evolution. As boilers increased in size and pressure, larger engines were built, and this increase in the available mechanical energy brought about the development of larger machine tools and more powerful manufacturing processes. Larger rolling mills and forges came into existence, new steels were developed, riveting machines came into the picture, and so gradually the whole mechanical technique developed until the early years of this century when we find a more or less standardized steam engineering technique throughout the world.

It was in the years around 1900 that steam engineering was about as standardized as it had ever been or as it has been since. Both the fire and water tube boiler had reached a stage of development where pressures up to 200 lb. were in general use and the Corliss engine was the choice prime mover.

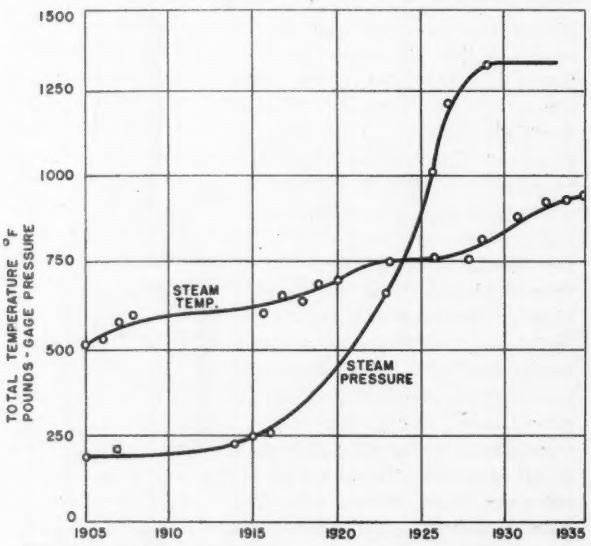


Fig. 1. Curves showing the rise of pressure and temperatures during the last 30 years

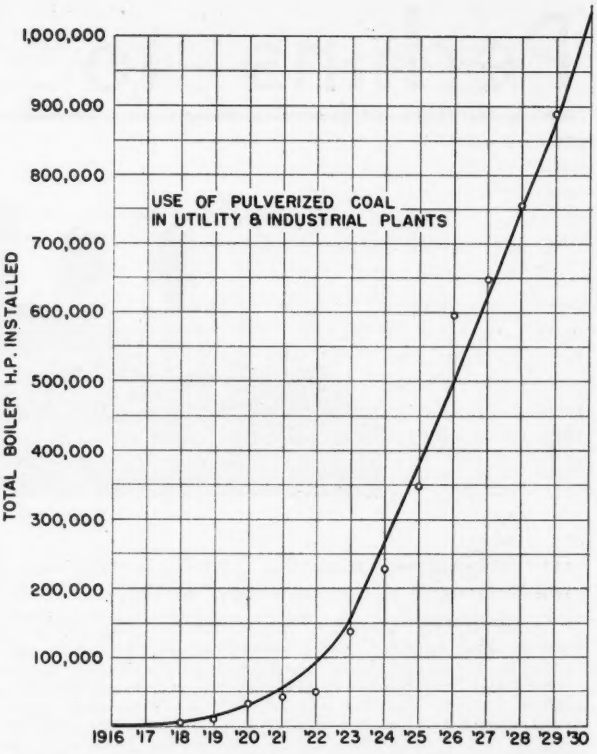


Fig. 2. The great increase in the use of pulverized coal started about 1920

Hand firing was the rule but the idea of automatic stoker firing was growing and the first stokers were in practical use. From that time on, until about 1920, was the period of automatic stoker development, progress following along two lines, that of the chain grate and that of the underfeed. In the meantime, as larger stokers eliminated the necessity of much hard hand labor, larger boilers were developed and the use of superheat became general in the larger plants. As shown by the accompanying curve, there was a gradual increase in the available steam temperature since 1905.

The successful operation of automatic stokers and the limited use of oil led some to toy with the idea of buring coal in pulverized form in large boiler plants. Like so many other things, the idea of using pulverized coal is not of recent origin. A patent for burning pulverized charcoal was granted to Sir Samuel Dawes as early as 1831 and in the century between that time and now many other experimenters tried it. It reached a point of successful development in the cement industry before it found general use in power plants. Shortly after the war, however, it began to be applied in power plant practice and since 1920 its development has been extremely rapid. The use of pulverized coal, once the early mental hazards had been removed, provided a highly efficient and extremely flexible methods of burning fuel which was capable of instantaneous response to changes in load through the use of automatic control equipment.

The importance of automatic control in boiler plant operation must not be underestimated. It would be

almost an impossibility to operate large boilers properly without some form of automatic combustion control and the development of the systems in use today to a certain extent at least has brought about the development of the steam generators they control. A modern steam generator is a sensitive device, containing little water compared to its steaming capacity and its adjustment to varying conditions of load must be brought about by automatic control apparatus regulating the fuel, water and air supplies.

Elementary and partial combustion controls have been in existence for over 100 years, yet complete automatic combustion control systems made little practical progress until the size of boiler units increased to the point where direct control was no longer physically possible and centralized remote control became necessary. Another factor of importance was the decreasing water content of modern boilers, the combined result of higher ratings and the reduction of drum diameters. Some modern boilers have only sufficient water capacity to run a couple of minutes at normal steaming capacities; thus giving feedwater control and regulation increased importance from the standpoint of boiler safety and stability and making instantaneous control of combustion imperative.

Thus combustion control systems developed hand in hand, so to speak, with modern boilers. The first automatic control device on a boiler was a simple draft regulator connected to the stack damper and later also to the turbo blower used for forced draft. A further step was taken when the control was extended to the stoker. Where both stokers and forced draft were used it was found necessary to add a second regulator—one controlled from the steam pressure and the other from the furnace pressure. As boilers became larger and more complicated, the controls also became more elaborate until today, we have the large and efficient units operating automatically under almost superhuman automatic control.

Pulverized coal as fuel was admirably adapted to automatic control and the advent of this type of fuel in the larger power plant gave impetus to the development of combustion control systems. Twenty years ago pulverized coal was hardly heard of in the power field while today the majority of medium and large plants are designed for this type of fuel. Reports from three principle boiler manufacturers show that of 335 boilers installed in the last five years, of 100,000 lb. per hr. capacity and above, 182 were pulverized coal fired, 67 were stoker fired, 60 were fired with gas or oil and 26 were fired with mixed fuels.

The necessity for higher pressures and temperatures in large steam generators brought designers up against the same difficulties that put an end to Jacob Perkins' work on high pressures and temperatures a century before. But much had been accomplieshed since Perkins' time; the whole science of metallurgy had developed, steel had come into large scale production and new methods of fabricating had become available that made possible constructions that Perkins and Watt in their wildest dreams could not have foreseen. In Watt's instructions for producing pressure tight seams he suggested the use of urine to cause corrosion in the joints of the boiler shell.

These developments, that of the automatic stoker and the successful burning of pulverized coal together with automatic combustion control made large boilers possible. There are many living today who can still remember the atmosphere of the old time boiler room —dark, dirty places filled with large numbers of grimy, sweating workmen, stripped to the waist, laboring often almost to the limit of human endurance. These things were possible with boilers of a few hundred horsepower but they would not have been possible with units of thousands of horsepower delivering hundreds of thousands of pounds of steam per hour.

A direct factor in the development of the high pressure boiler was the perfection of the art of fusion welding. As the pressures increased, the required wall thickness of steam drums became so great that the seams could no longer be riveted. Drums were then forged from solid billets but they were found very costly and proved a deterrent to the installation of high-pressure boilers. With the rapid advance in the art of welding and methods for testing and investigating the strength of welds, it became possible to construct at reasonable cost welded drums, which could be considered perfectly safe for boiler work. Since the rules for fusion-welded drums were adopted by the A.S.M.E. Boiler Code Committee in 1931, the use of high-pressure steam has become well established and boilers of 1400 lb. are as common today as were 400 lb. pressures ten years ago. In this adoption of welding the use of the X-ray was an important factor. An electrically welded joint, no matter how perfect it may appear to be from the outside is always subject to suspicion as regards its internal structure, and this fact was responsible for considerable reticence on the part of boiler users to accept welded drums. With the systematic and routine examination of welded seams by radiographic methods and the employment of thermal stress-relieving treatment, the element of doubt concerning the efficacy of welds was removed and as a consequence the use of welding became accepted practice in high pressure boiler manufacture.

As steam pressures increased the advantages of higher temperatures became more apparent. A very brief study of the steam charts will show that the thermal advantage of increasing the initial steam pressure is definitely tied to the assumed maximum steam temperature. At any given assumed initial steam temperature, either with or without reheat, increasing the steam pressure from a low value causes a thermal saving, but the rate of increase of this saving decreases as the pressure rises, until finally there is reached a pressure beyond which improvement is insignificantly small. This point moves up to higher pressures as the assumed initial temperature is increased. At the present time we are operating our highest temperature boilers at around 900 deg. F. and with pressures in the 1200-1400 lb. region. Assuming now that successful operation is possible at 1000 deg. F. we would obtain a new set of values and so on.

At the present time one large unit is being built for operation at 940 deg. F. and temperatures of 1000 deg. have been tried in a limited way. Such temperatures, however, present a major problem in metallurgy and while much excellent work has been done, much still remains to be done in this field. At temperatures

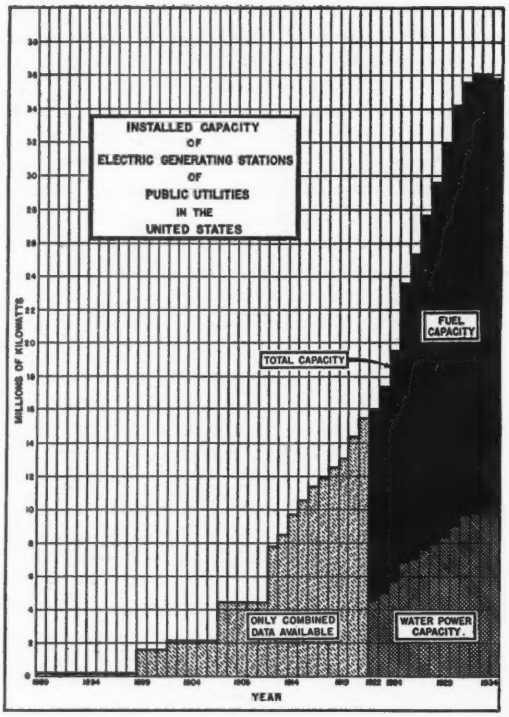


Fig. 4. Installed capacity of electric generating stations of Public Utilities in the U. S. by years 1889-1934

of 900 and 1000 deg. the metal in contact with the steam is red hot and is subject to the action which has been called creep, that is, the permanent elongation of the metal with time. Much excellent research has been done and more is being done on the creep properties of steel and while progress is slow steels are being pro duced which are capable of being used at temperatures in the range between 900 and 1000 deg. F. with good success.

As indicated above the use of high pressures is definitely related to the steam temperatures and with a definite limit to the maximum initial temperature of the steam, little or no gain can be expected from still higher pressures unless re-heat is resorted to.

The use of re-heat was quite common in the stations of eight and ten years ago when pressures were around 750 lb. and steam temperatures were below 750 deg. F. As pressures increased to 1200 and 1400 lb. reheating was still desirable as long as the initial temperature remained around 750 deg. but when temperatures began to go up, the thermal advantages of re-heat decreased somewhat and for a while re-heat practice went into the discard. At the present time, however, with temperatures up around 900 deg. F. and pressures at 1200 to 1400 lb., little gain can be expected in going to pressures over 1400 lb. unless re-heating is resorted to. It is, therefore, of considerable interest that in the new 2500 lb. boiler for Twin Branch recently announced and which will operate at 940 deg. F. the re-heat cycle will be used again.

In all this we have said little about the construction of the modern boiler as it has evolved from the type in vogue in the early nineteen twenties. As the furnaces called for higher heat releases, water cooled walls were developed to absorb these releases and to eliminate the refractory problem. This surface in effect was taken from the boiler and decreased the size of the boiler proper. As steam temperatures increased, the superheaters became larger and in part were placed in the furnace. This again made the boiler proper smaller. So also the development of larger air preheaters and economizer sections made that part of the unit devoted to the evaporation of water still smaller, so that today in some of the large units only a vestige of the boiler itself remains. In some of the standard units, the boiler heating surface proper is only 7 per cent of the total, while in the so-called radiant type boiler there is practically no convection boiler heating surface at all. This has not changed the boiler fundamentally, what has happended is that there has been a re-arrangement of the heating surface into divisions each of which is adapted to some special function. Essentially, the steam generator of today is as it has been from the beginning in this country. Steam drums and thermal water circulation are still used practically

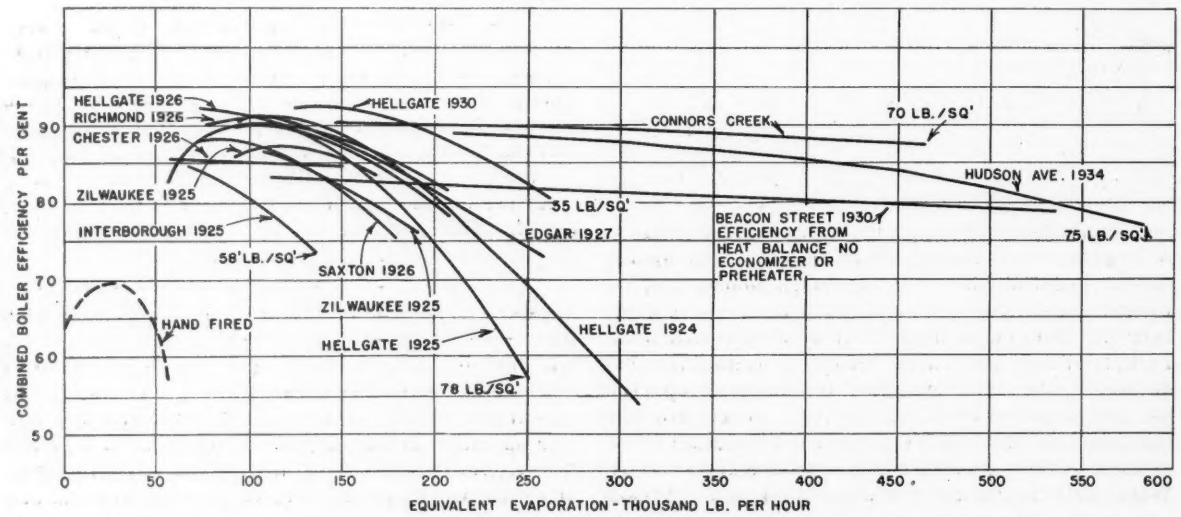


Fig. 5. Curves showing the trend in stoker design. As will be seen, the maximum efficiencies have not changed but the efficiency curves of the more recent stokers are much flatter, indicating a high efficiency over a much greater range of load

without exception. In other words, the development here has been along slow evolutionary lines; in no case have we ventured far into the unknown.

In continental Europe the move toward higher pressures and temperatures has been made along different but equally characteristic lines. There the engineers endeavored to analyze in advance all the factors which might be expected to enter into the problem and then to produce designs which would properly take account of these new factors. They anticipated certain difficulties as the result of such analyses.

Some few European designers and builders have gone ahead as we have with more or less conventional types. Others have contemplated this long list of factors of unknown weight and created new designs. Thus the inventer of the Atmos boiler anticipated difficulties in heat transfer between metal and water and adopted a rotating boiler tube with provision for most intimate contact between water and metal. In the case of the Benson boiler, the inventor attempted a unique and striking solution. He made his boiler nothing but a water heater without drums or steam space. In still another direction, the Schmidt boiler consists of two boilers operating at different pressures. The boiler operating at the higher pressure is filled with distilled water which never leaves it. This water is converted into steam and is then condensed in coils immersed in water contained in the lower pressure boiler, the condensate running back automatically to the boiler in which it was made. The distilled water then serves merely as a heat transferring device and protects the surfaces exposed to the fire from the effects of scale deposition.

Whether these new types of boilers point the way to future progress in steam generation or whether this progress will follow along the lines of conventional practice is too early to tell. It is not too early, however, to study these new types in the light of our requirements and to see whether they hold anything of promise to us.

In the meantime, the development on this side of the Atlantic is on a sounder basis than it has been for many years. Many of the troubles encountered in the early development of the modern high pressure unit are disappearing and a well defined technique has evolved.

In the case of pulverized coal firing two types of furnaces are in general use, one the so-called dry bottom type which disposes of the ash in dry granular form and the other the wet bottom furnace in which the temperature is kept high enough to liquefy the ash. The latter has some advantages in that it entrains a certain amount of fly ash that would escape from a boiler with a dry bottom furnace but it also has limitations as regards the rating at which boilers can be operated. The slag tap furnace is a startling development, one difficult to imagine until it happened more or less accidently at Huntley Station in Buffalo in 1926. Furnaces are further classified according to whether they are of the closed or open type and whether the slag is tapped off intermittently or continuously.

Along with pulverized coal development, stoker development has proceeded at a rapid rate. Where formerly 40 to 50 lb. of coal per sq. ft. of stoker grate surface was considered maximum, today as much as 85 lb. per sq. ft. can be burned. This increase was brought about largely by better control of air distribution through the fuel bed. For use with low fusion ash coal, water cooled stokers have been developed which so far have given good performance. Stoker efficiencies have not changed materially in recent years but the efficiency curves are flatter, showing that high efficiencies are maintained over wide range of output.

In both the pulverized coal as well as the stoker fired units, much of the boiler heating surface is in the water walls. This practice which was first tried out commercially about 1923 has become almost universal.

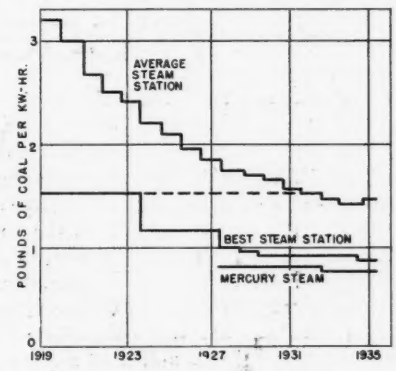


Fig. 6. Full consumed per unit of electric power produced in the United States from 1919 to 1935, inclusive

If the water wall has grown in importance in recent years so also has the superheater. Once a mere incident in the design of the unit as a whole, it is now an element of major importance and one intimately related to the control problem.

Thus, the modern steam generator consists of a boiler section, usually a small part of the total heating surface, a water wall section, an economizer section and the superheaters. An air preheater is also a feature of all present day units but usually this is external to the unit proper.

As mentioned elsewhere in this issue, this combination of elements disposed in proper fashion results in a complicated mass of tubes and drums which is bewildering to the casual observer and the question may well be asked whether it is necessary.

The answer to this question at present is yes. Today we know of no way of doing the thing in simpler fashion, though by this we do not imply that some simpler method may not be discovered in the future. With the high pressures in use small tubes are a necessity and with steaming rates up to a million pounds per hr. a large number of such tubes is unavoidable. Even with present designs, the speed of the steam through the superheater is 500 ft. per second with pressure drops of 50 to 75 lb. across the element.

In conclusion, it may be stated that boiler operation has never been more reliable than it is at present with these modern units. Today boilers are kept on the line for months and even years at a time. At Port Washington Station the availability of the boilers this year has been over 83 per cent but this figure is misleading since the outage time includes the time needed for regular inspection. In other cases the availability of boilers has been well over 90 per cent and the new units at Logan are designed for an availability of 50 weeks out of the 52 in a year.

For the smallest power boiler and the largest steam generating unit, the principles of heat absorption are the same, materials used and construction details employed vary with temperatures and pressures

Features of Modern Steam Generators

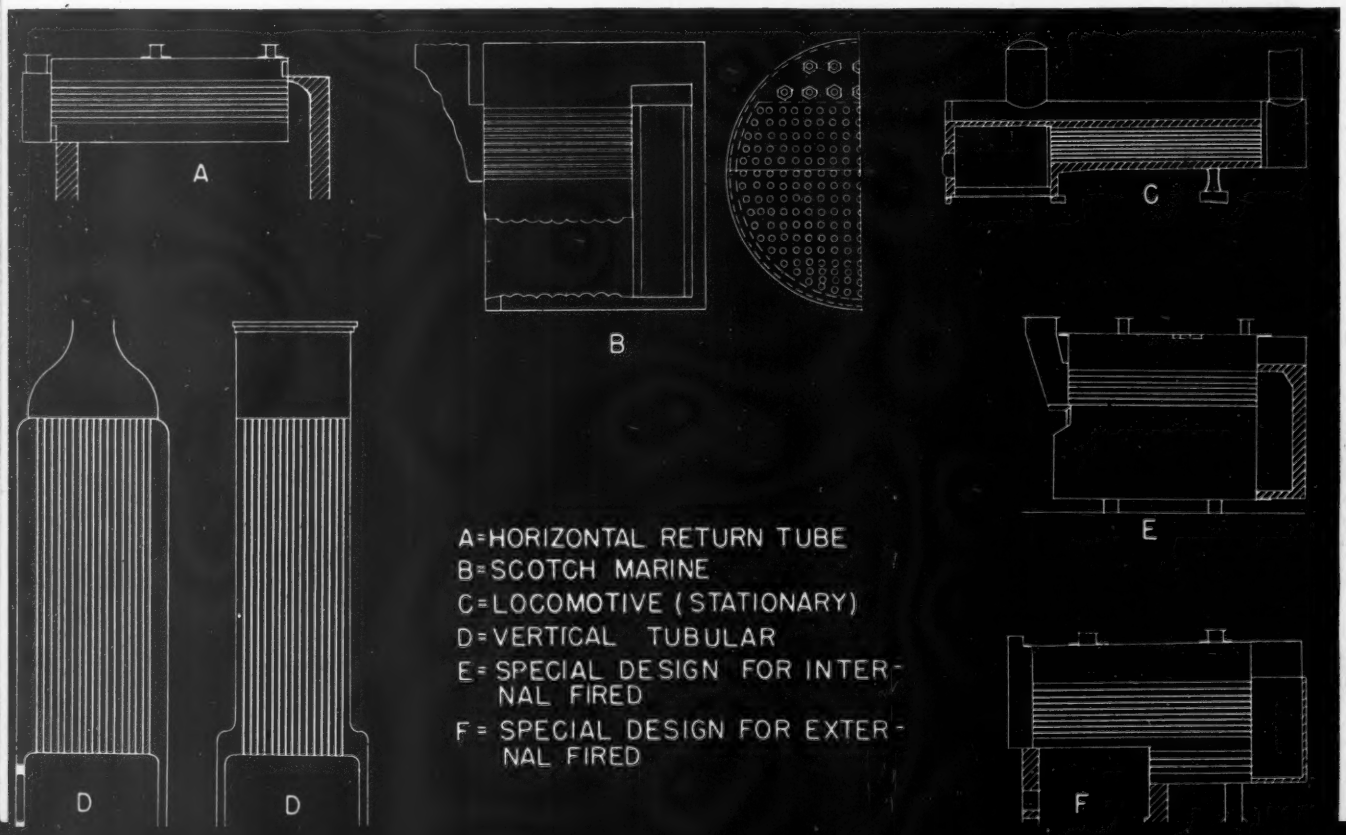
FROM the early days of the Christian era the vessels used for containing water while boiling under pressure have undergone continual change clear down to the present with no indication that the end is in sight, for engineers are still striving to capture those last few elusive heat units that struggle through networks of tubes to dissipate themselves in Nature's leveling processes. Engineers have stopped at nothing conceivable in the way of design which indicated any promise whatever of improving the steam generating equipment of the day. Both empirical and theoretical methods have been employed in this long continued evolution of equipment to convert latent heat of fuel into dynamic energy represented by steam at high pressure and high temperature. Through this evolution many fundamental laws have been discovered and it is not surprising that features of the earlier designs of boilers have remained prominent.

Fundamentally the purpose of a boiler is to provide a receptacle in which water may be converted into steam. In practice heat is supplied by the burning of fuel and must be transmitted through the walls of the container to the body of water. As the water is changed into steam due to absorption of heat, the pressure within the vessel will continue to rise with the addition of heat until some of the steam is allowed to escape either by conveying it to steam using equipment or through safety valves used to prevent excessive pressure.

As the steam leaves the boiler more water must be pumped in, thus providing a continuous inflow of water and a corresponding outflow of steam. To this water in the boiler must come the heat generated by the combustion of fuel, the path of this heat is through the containing wall of the boiler. The most efficient boiler is that which will transfer the greatest percentage of the heat in the fuel into water and steam within the vessel. Upon these few fundamentals the entire art of steam generation has been built.

Equipment used for steam generation in modern prac-

Fig. 1. Various types of fire-tube boilers



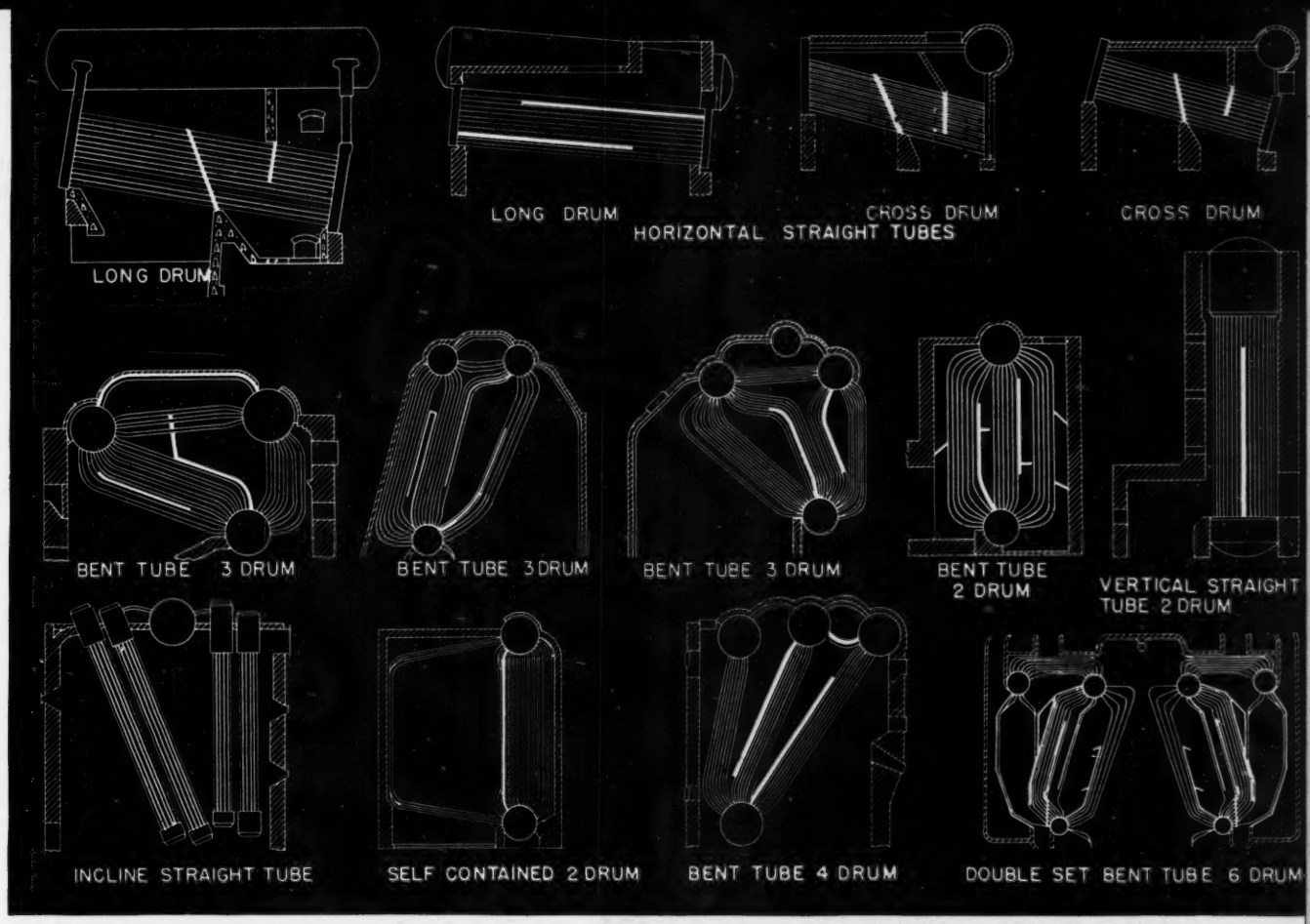


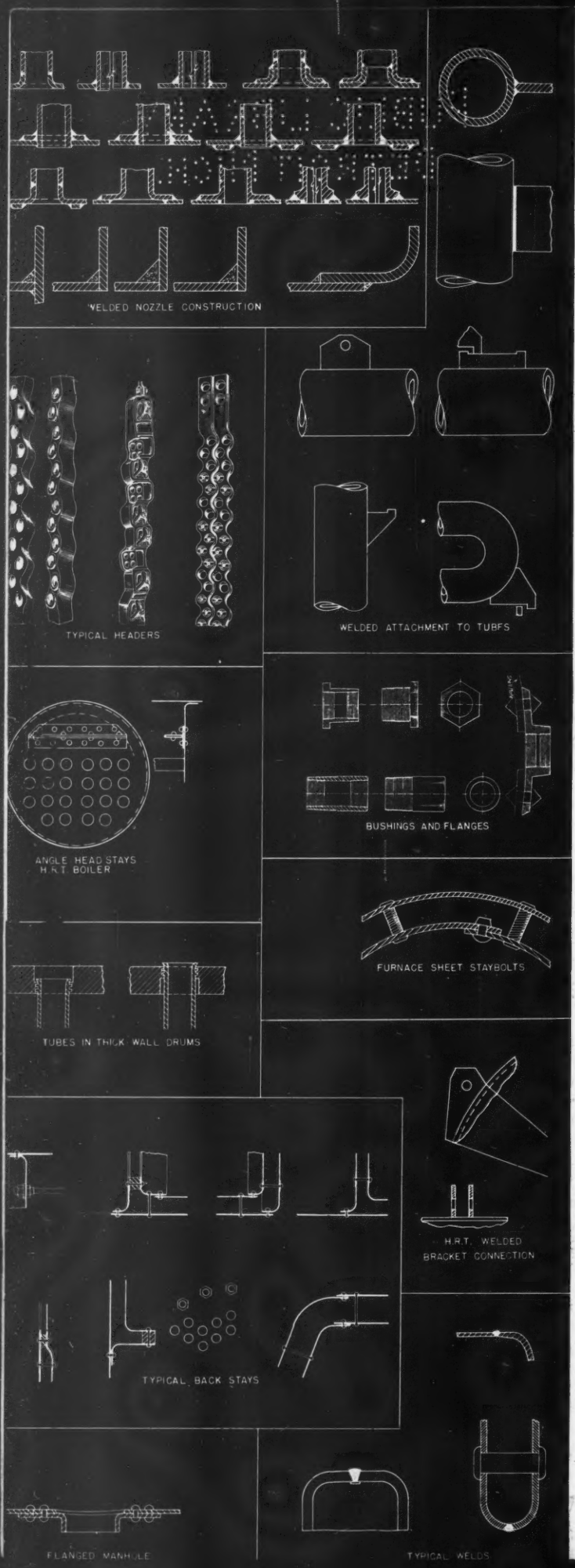
Fig. 2. Water-tube boilers of various types

tice falls into two general classifications: 1. That in which the principal heat absorbing surface is arranged in tubes with the hot gases of combustion passing through the inside and the water contacting the outside surface. These are called fire-tube boilers. 2. Those arranged with the water circulating through the inside of the tube and the hot gases on the outside, called water-tube boilers. A further convenient breakdown of this classification of power boilers is as follows:

1. Fire-tube
   - a. Horizontal return tubular
   - b. Scotch marine
   - c. Locomotive-stationary
   - d. Vertical tubular
   - e. Special design horizontal internally fired
   - f. Special design horizontal externally fired
2. Water-tube
   - a. Horizontal, straight tube, longitudinal drum
   - b. Horizontal, straight tube, cross drum
   - c. Vertical, straight tube, 2 drum
   - d. Bent tube, 2 drum
   - e. Bent tube, 3 drum
   - f. Bent tube, 4 drum
   - g. Inclined straight tube
   - h. Bent tube, 4 drum, radiant element
   - i. Bent tube self contained unit, 2 or more drums
   - j. Double set bent tube with 5 or more drums

Each of these types of boilers is shown by typical examples in the accompanying drawings. It must be recognized that the designing of boilers is always a compromise for a complete set of ideal conditions that never exists and there is always the question of how far it is economically possible to go in providing extra equipment to secure higher efficiency. Engineers years ago formulated a set of ideal requirements toward which they aim in their design work, these as slightly revised for modern conditions and reported by Terrell Croft are:

1. Proper workmanship and simple construction, using materials which experience has shown to be the best, thus avoiding the necessity of early repairs.
2. A mud drum or header to receive the impurities deposited from the water and so placed as to be removed from the action of the fire.
3. A steam and water capacity sufficient to prevent any material fluctuation in steam pressure or water level.
4. A water surface, for the disengagement of the steam from the water, of sufficient extent to prevent priming.
5. A constant and thorough circulation of water throughout the boiler so as to maintain all parts at as nearly the same temperature as possible.
6. A form of construction which will obviate, insofar as is humanly possible, the liability of dangerous explosions.
7. A great excess of strength over any legitimate strain. The boiler should be so constructed as to be free from strains due to unequal expansion. If possible, joints exposed to the direct action of the fire should be avoided.
8. A combustion chamber so arranged that the combustion of gases started in the furnace may be completed before the gases escape to the boiler.
9. A disposition of the heating surface, relative to the direction of flow of the gases of combustion, that will



insure the greatest possible transfer of heat to the water in the boiler.

10. Ready accessibility to all parts for cleaning and repairs.

11. Proportionment for the work to be done and capability of operating to its full rated capacity with the highest attainable economy.

12. An auxiliary equipment comprising the very best gages, safety valves and other fixtures.

13. A setting that will insure maximum efficiency of combustion, minimum maintenance and that will obviate to the highest attainable degree losses of heat by radiation and impairment of the furnace efficiency by the infiltration of air.

Among fire-tube boilers, the return tubular type stands out as the fundamental design upon which others in this class in use today are based, although it was the outgrowth of tubular designs that have long since passed out of industrial use. Extremely simple in design, the boiler consists of a horizontally placed cylindrical shell closed at each end with a tube sheet in which holes are punched for the insertion of tubes. These run from end to end where they are rolled into the tube sheets and beaded so as to make a steam tight joint. The number and size of the tubes vary with the size of the boiler from about 24 to 110, 3 to 4 in. tubes, the shells varying from 36 to 96 in. in diameter. The tubes occupy space in the lower two-thirds of the drum, leaving room below them for inspection and cleaning. Access is gained to the interior through manholes. Openings in the shell must also be provided for the steam outlet, safety valve, pressure gage, gage column, feedwater and blowoff.

These boilers are used extensively in the heating field and in small industrial plants where the pressure carried does not exceed 125 lb. per sq. in., where the steam demand is reasonably steady, the pressure regulation not too exacting and the space available is not limited. Horizontal return tubular boilers have the greatest amount of heating surface per unit volume of water contained of any of the tubular boilers, the circulation of the water is crosswise of the tubes through which hot gases are passing, making the boiler a ready steamer, and they are the least expensive to construct. Their disadvantages, some of which are corrected in other types of fire-tube boilers, are summarized as follows: They offer an element of weakness in design by having a riveted girth seam exposed to direct heat of the fire. Scale accumulation takes place on the shell directly over the fire. Hot gases tend to short circuit through the upper rows of tubes. The horizontal tubes easily become clogged with soot and fly ash. Tube surfaces on the water side are difficult to clean and inspect. Unless specially designed, water circulation is liable to be sluggish.

The vertical fire-tube boiler with an internally fired furnace keeps the intense heat away from the shell and does away entirely with the brick setting. It also provides a certain amount of superheating, thus insuring dry steam to equipment. Furnace strains, however, are liable to occur resulting in leaks and headway must be allowed for the removal of tubes. Internal firing has the advantage of reducing radiation losses, also the losses due to air infiltration but the choice of fuel is limited to that which will burn completely in the limited combustion space available.

Fig. 3. Details of construction used in the design of modern boilers

The danger in h.r.t. boilers from over-heated girth joints has been overcome in recent years by welding the plates. Internal firing in corrugated furnaces has been used in horizontal boilers which relieves the shell and does away with stay bolts. This design also causes the sediment to be deposited in the coolest part of the boiler. Arranging the tubes so as to provide vertical water lanes has done much to improve boiler water circulation.

In the construction of fire-tube boilers, steel plates of the required thickness, width equal to the circumference of the boiler shell and length equal to that of the desired section, are rolled to a diameter that will permit the various sections to be slipped within each other at the ends to form the girth seams when riveted joints are used. Girth seams are usually lapped and longitudinal seams of the butt strap type. Tube sheets are cut to circular form, the holes punched, the sheets crimped at the edges and riveted to the shell. Stay bolts and braces are then fastened in place and the fire-tubes, following reaming of the holes, are inserted and rolled and beaded to a steam tight fit at each end. With these boilers, shop fabrication is employed throughout, leaving only the setting, where necessary, and the accessories to be attached when the boiler is installed.

Water-Tube Boilers

By putting the water on the inside instead of the outside of the tubes, engineers have found many advantages not only in the flexibility permitted in design, but in the increased safety in the operation of the equipment, possibility of higher pressure, better steaming qualities, greater capacities obtainable, and the ability to place in one unit all equipment necessary for the generation of steam from the heated feedwater to the highly superheated steam and the entire fuel burning equipment.

The classification of water-tube boilers as given here has to do only with the boiler proper, i. e., that section of the steam generating unit designed especially for the final heating of the water and the liberation of the steam. Other sections of the steam generator, including furnaces, economizers, air preheaters, superheaters and reheaters, are given special treatment in separate articles on following pages. The purpose here is to give a general picture of various arrangements of equipment and details of construction which have made these arrangements possible.

In the accompanying illustrations the various types of water-tube boilers from the simplest to the most comprehensive are shown. In size they will serve any industrial needs up to as high as 1,250,000 lb. of steam per hr. from a single unit, pressures now in actual use in the United States range as high as 1800 lb. with plans under way for a unit to be operated at 2500 lb. Final steam temperatures of 950 deg. F. are being used successfully.

Straight inclined tube boilers of the simplest designs may have drums placed either longitudinally or crosswise, in either case the tubes must be rolled into headers either of the box or some form of sectional type. Because of structural difficulties boilers employing box headers are limited to pressures of about 300 lb. and the capacity is limited by the size of the opening between the header and the drum. In the case of sectional headers the connection to the drum is through tubes and a cross box which permit economical construction for higher pressures. For larger capacities two or more longitudinal drums may be used.

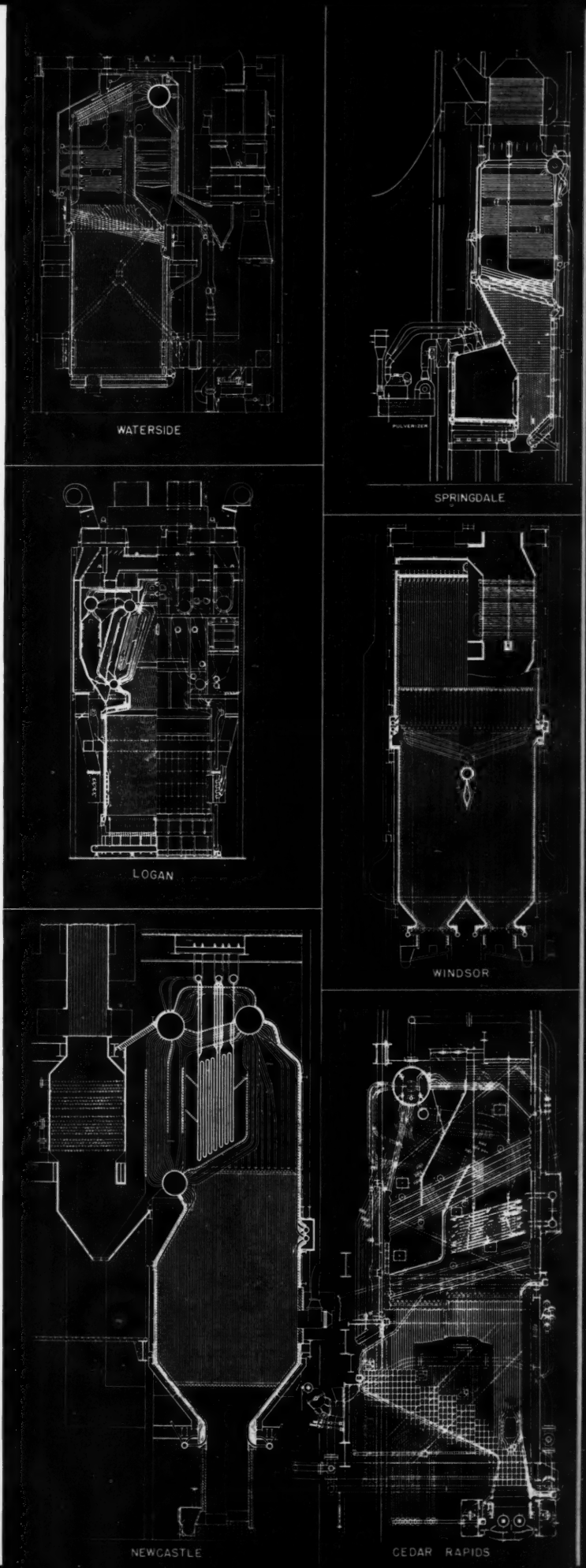


Fig. 4. Steam generating units typical of modern design

Table 1. Properties of various grades of steel and iron used in boiler construction*

Material	Where used	Chemical properties			Sulphur, maximum, per cent	Physical properties					
		Carbon, maximum per cent	Manganese, per cent	Phosphorus, maximum per cent		Tensile strength, lb. per sq. in.	Yield point, lb. per sq. in.	Elongation, per cent		Reduction area, minimum per cent	Special tests
								in 8 in. at least	in 2 in.		
Steel Firebox (plate)	Parts exposed to fire and under pressure; also other plate	Less than ¾ in., 0.25; over ¾ in., 0.30	Less than ¾ in., 0.30–0.60; over ¾ in., 0.30–0.60	Acid, 0.05 Base, 0.035	0.04	55,000–65,000	0.5 tensile strength	1,500,000 / Tens. str.			Bend homogeneity
Flange (plate)	For parts when fire-box quality is not specified; manhole and handhole covers		0.30–0.60	Acid, 0.05 Base, 0.04	0.05	55,000–65,000		Min. = 20%			Bend
Rivet	Rivets		0.30–0.50	0.04	0.045	45,000–55,000		1,500,000 / Tens. str.			Bend, quench, and cold
Stay bolt	Stay bolts		0.30–0.50	0.04	0.045	60,000	36,000	Max. = 30%			Bend, quench, and cold
Bars	Braces, and other bars not otherwise specified			Acid, 0.05 Base, 0.04	0.05	55,000–65,000	0.5 tensile strength	1,500,000 / Tens. str. Min. = 18%	26 min.		Bend
Tube, lap-welded and seamless boiler grade *A*	Lap-welded tubes and all seamless tubes	0.06–0.18	0.30–0.60	0.04	0.045						Flange flattening; hydrostatic
Castings Class A	Water leg and door-frame rings	0.45		Acid, 0.07 Base, 0.06							
Class B	Cross pipes, headers, cross boxes, and pressure parts over 2-in. pipe sizes; mud drums; parts of superheaters; water leg and doorframe legs			0.05	0.05		29,250		1,600,000 / Tens. str. Min. 24%	2,600,000 / Tens. str. Min. 35%	Destruction
Iron Rivet	Rivets					48,000–52,000		28		45	Bend, cold, nick, and etch
Stay bolt	Stay bolts					48,000–52,000	0.6 tensile strength	30		48	Bend, cold, quench, nick, and etch
Refined wrought bars	Braces when welded					48,000–54,000		25		37	Bend, cold, hot, nick, and etch
Charcoal iron	Lap-welded tubes										Flange; flattening; hydrostatic
Malleable castings	Cross pipes, headers, cross boxes when pressure is less than 200 lb. per sq. in. and section within 7 by 7 in.			0.225	0.06	50,000	32,500		10		
Gray castings Light	Boiler and superheater mountings, pipes, fittings, valves for temperature less than 450°F.; headers in water-tube boilers	(Any section less than ½ in. thick)			0.10	18,000					Transverse
Medium		(Castings not included in Light and Heavy)			0.10	21,000					
Heavy		(No section less than 2 in. thick)			0.12	24,000					

* From 1933 A.S.M.E. Boiler Code.

Box headers are made of steel plates riveted or welded together to form a box about 8 in. deep and braced with stays. These plates have holes punched and reamed on one side to receive the tubes and on the opposite side are handholes giving access to the tubes for rolling, replacement and cleaning. These headers must be perpendicular to the tubes and therefore at an oblique angle to the drum if it is set horizontally. Some designs have the drum as well as the tubes set on an incline. In either case the box header must be shaped at the top to fit the drum and there riveted or welded around holes provided for the passage of water and steam. The rear box header is usually attached to the drum through down comers and a cross box attached to the drum. These down comers also provide a gas outlet to the breeching.

By dividing the header into vertical sections, each section providing a passage for steam and water from one or more staggered vertical rows of tubes to the drum, no stays are necessary and the tube side can be forged so that the surface at each tube connection is perpendicular to the tube while the center line of the header remains vertical.

Cross drum boilers with straight inclined tubes have the headers connected to the drum through bent or straight tubes, depending upon the location of the drum, thus overcoming the structural difficulty of attaching the header to the drum. These tubes enter the drum at right angles to the surface and are expanded to make a steam tight fit. At the lower end of the rear water leg some form of mud drum or space is provided where sediment may settle out of circulation and be drawn off at intervals through the blowoff connection.

Straight water tubes in boilers of these general designs are usually 4 in. in diameter when intended for low pressure use but the size is reduced as pressures are increased, some designers preferring 3½-in. tubes for pressures between 500 and 900 lb., and above that 3¼-in. tubes. The smaller tubes are quicker steamers but present greater resistance to the flow of water and are more easily clogged with scale. Straight tubes attached in multiple to a single header or section present expansion difficulties that limit their length, which in practice ranges between 18 and 26 ft.

Straight vertical tubes are used in several designs of boilers that do away with headers entirely, the tubes being expanded into the heads of the drums placed with axes in line with the nest of tubes.

When the use of bent tubes for boilers became practicable, which was delayed somewhat by the difficulty of keeping them free of scale, the foundation was laid for the development of designs along the lines of the present high-pressure, high-temperature and high-capacity

steam generating units. High pressures can be provided for by reducing the tube and drum diameters without increasing the wall thickness beyond practical limitations. High temperatures have required the development of special alloys, but the bend in the tube provides for expansion and contraction without undue strains on joints and boiler parts. Space requirements and economic consideration seem now to be the only limiting factors in the design of boilers for capacity.

With bent-tube boilers, heating surfaces are placed where they are most effective in absorbing heat either radiated from the burning fuel or carried from the furnace by the gases as convection heat.

Boiler tubes for these designs are usually 3¼ in. in diameter for pressures below 500 lb., 3-in. tubes are used by some manufacturers for higher pressures, while others employ tubes as small as 2 in.

Various common arrangements of tubes and drums of bent-tube boilers are shown in the illustrations. The number of drums varies from two to as many as ten and many of the designs include manifold headers into which water-wall and superheater tubes are expanded. Two and three drum boilers of a size that can be shipped are usually fabricated at the factory, larger units, however, must be assembled at the plant. All refractory and brick work must, of course, be laid at the plant.

Drums for water-tube boilers are essential as headers for the tubes forming the heating surface and as space in which the steam may be released from the water, they do not, as a rule, present much if any surface for the transmission of heat, so considerable freedom is left the designer in the choice of joint and the thickness of the plate.

Drums for this use may be either formed from rolled sheets and riveted or welded, as is done with tubular boilers, or they may be forged from a solid block of metal, pierced and formed to the proper shape and size. Tube holes are drilled in a multiple drill press and reamed to the exact size desired. When drums are fusion welded, modern practice demands X-ray examination of the joint and stress relieving in an annealing furnace.

Tubes used in the construction of boilers may be either welded or seamless drawn, the material used being such that it will withstand the temperatures to which it will be subjected and can be expanded and beaded into the header or drum. It should be a good conductor of heat and capable of resisting corrosion both on the water and the gas sides. Walls should be as thin as possible consistent with the service to which the tubes are put. Properties of various grades of steel and iron used in boiler construction have been specified by the A.S.M.E. and are given in Table I reproduced here from the Boiler Code. Additional information is given in Table II compiled by the National Tube Co. These creep test values are much lower than those for short-time tensile tests at high temperatures. Creep tests are conducted by heating the specimen to a definite temperature and applying a definite fixed load. Elongation measurements are recorded daily for a period up to 10,000 hr. It has been found that under static loads, metals flow at stresses which are much less than the short time strength at similar temperatures.

Table II. Creep properties for 1 per cent elongation in 10,000 hours at various temperatures

Type		Pounds per square inch stress							
		800° F.	900° F.	950° F.	1000° F.	1100° F.	1200° F.	1300° F.	
1. Low Carbon	a. Open Hearth	15000	9000	6700	4500	1500	400	....	Note I
	b. Electric	21500	11500	8500	5750	1800	600	....	Note II
2. Low Carbon .50 Mo.	a. Open Hearth	25000	17000	12500	8500	3400	1300	....	Note I
	b. Electric	26000	22100	16400	14000	6500	2000	....	Note II
3. Low Carbon 1. Mo.	a. Open Hearth	26000	18100	13500	9200	4200	1200	....	Note I
	b. Electric	29000	24000	17800	11000	5300	1900	....	Note II
4. 1.5 Sil. .50 Mo.	Electric	29500	19100	14000	9500	4700	1850	....	
5. 1.25 Chr. .50 Mo.	Electric	29000	21000	17000	13000	6500	2950	Under Test	Note III
6. 1.75 Chr. .70 Mo.	Electric	27500	19200	15500	12000	6500	2500	....	
7. 2. Chr. .50 Mo.	Electric	29000	18500	15000	11500	6200	2400	....	
8. 2.5 Chr. .50 Mo.	Electric	25000	17200	13000	8600	4900	2325	....	
9. 5. Chr. .50 Mo.	Electric	26000	18200	14000	10100	6000	3300	1500	
10. 5. Chr. .50 Mo. Stab.	Electric	26000	18200	14000	10100	6000	3300	1500	
11. 18-8	Electric	....	25000	21500	18500	12750	7800	4900	
12. 18-8 Stabilized	Electric	....	25000	21500	18500	12750	7800	4900	

NOTE I—Tests in these series performed on specimens in full annealed state and spheroidized structure in metal—open hearth steel.
NOTE II—Tests in these series performed on specimens in the normalized state—electric furnace steel.
NOTE III—Values given at 1000° F. based on test conducted for 8000 hrs. Tests lasting only 500 hrs. give values as high as 24000 lb. Retesting of this steel now in progress.
NOTE IV—Creep values for 1% elong. in 100,000 hrs. not given on account of inaccuracy of extrapolation to such long periods. Values for this creep seem to be approx. 60% of the load for 1%/10000 hrs.

Proportioning of Heating Surface

In the design of the simple tubular and water-tube boilers the practice usually followed has been to assume that all the heating surface in the boiler had about the same heat transmitting ability, so tubular boilers were rated on the basis of 12 sq. ft. to 1 boiler hp. and water-

(Continued on page 25)

Table III. Distribution of water and steam heating surfaces in typical modern steam generators

Station	Throttle Pres. lb./sq."	Throttle Temp. °F.	Capacity lb./hr.	Total water & steam Htg. Sur. sq.ft.	Boilers sq.ft.	Boilers %	Superheaters sq.ft.	Superheaters %	Economizers sq.ft.	Economizers %	Water Walls sq.ft.	Water Walls %
State Line	1200	825	500,000	53,866	8,135	15.0	11,500	21.4	31,191	58.0	3,040	5.6
" "	1200	825	385,000	33,886	8,135	24.0	8,025	23.7	14,686	43.3	3,040	9.0
Manchester St.	1200	925	430,000	40,050	8,100	20.0	8,600	21.6	16,650	41.7	6,700	16.7
So. Meadow	850	900	425,000	42,000	5,200	12.4	9,300	22.1	23,000	54.8	4,500	10.7
Delray	815	900	344,000	40,789	8,188	20.1	9,353	23.0	18,300	44.7	4,948	12.2
Morrow	800	850	400,000	49,500	7,400	15.0	9,500	19.0	28,500	57.7	4,100	8.3
River Bend	665	825	275,000	30,900	16,900	54.7	8,000	25.9			6,000	19.4
Mt. Creek	675	830	200,000	17,700	13,800	78.0	2,400	13.6	1,500	8.4		
Seward	650	825	200,000	31,507	16,320	51.5	5,825	18.5	8,320	26.5	1,047	3.5
Essex	1265	950	605,000	41,493	3,060	7.4	15,400	37.1	16,280	39.2	6,753	16.5
Logan	1265	925	1,000,000	92,950	20,800	22.5	26,000	28.0	25,850	27.8	20,300	21.7
Springdale	1200	925	500,000	47,425	6,369	13.4	19,070	40.1	16,700	35.2	5,286	16.3
Windsor	1265	925	750,000	65,840	7,717	11.5	15,580	23.7	34,600	53.0	7,743	11.8
"	1265	925	750,000	49,560	13,000	26.2	18,400	37.1	11,000	27.3	7,160	14.4
Schuylkill	1265	900	600,000	47,080	11,090	23.6	16,300	34.6	11,500	24.5	8,190	17.3
Millers Ford	1200	900	375,000	37,650	3,400	9.0	10,800	28.6	20,650	55.0	2,800	7.4
Austin	400	750	80,000	14,612	9,600	65.7	3,900	26.7			1,112	7.6
Rochester	400	650	125,000	13,890	10,190	73.4	1,750	12.6			1,950	14.0
Ottawa St.	825	900	225,000	19,800	2,800	14.1	7,000	35.2	6,800	34.6	3,200	16.1
Albert Lea	295	520	40,000	6,350	4,900	77.2	400	6.2			1,050	16.6
South Works	450	750	300,000	41,305	22,000	53.3	6,450	15.6	7,180	17.4	5,675	13.7
Charleston	550	700	225,000	19,950	11,400	57.1	2,050	10.3			6,500	32.6
Midland	1250	825	300,000	41,160	3,510	8.5	4,950	12.1	27,800	67.5	4,900	11.9

Boiler furnaces must also give its guest a warm welcome, fresh air, a dizzy whirl and a clean exit

FUELS NEED ROOM TO BURN

AS DESIGNED for use with power steam boilers, furnaces perform a number of services. (1) They must be provided with a place on which the fuel rests while being burned, in cases where solid fuel is being used. (2) In all cases, space must be provided for the combustion of gases, either as distilled from the fuel bed, from the pulverized fuel particles, or from atomized oil vapor. Fuel gas burns without preliminary change. (3) Nearly all solid fuels leave ash or clinker, removal of which must be provided for. (4) Furnace walls are required to prevent radiation to surrounding atmosphere. (5) Furnace arches and walls are designed to reflect radiant heat so as to aid combustion. (6) Walls are designed for admitting and directing the course of combustion air. (7) Furnace walls and arches are used to direct the course of the burning and spent hot gases to the heating elements of the boiler.

When burning steam or larger sizes of coal, considerable time is required for the particles to burn completely. First the volatile gases must be distilled off by heat supplied by the furnace, the remaining coke is brought to the kindling temperature and, due to the heat and close contact with air, burns to form furnace gases leaving the ash to be removed. During this process some provision must be made to hold the fuel bed practically suspended in air. This is accomplished by providing grates or stokers built into the furnace. Features of these and other burning equipment are discussed in a succeeding article.

During combustion, all solid and liquid fuels form gases. These combustile gases must be thoroughly mixed with air in order to burn completely. Sufficient space between the ignition point of the fuel and the comparatively cold heating surface of the boiler must be provided for the thorough mixing of combustible gases and air or unburned gases will become chilled below the ignition temperature and pass to the chimney as an avoidable waste accompanied almost invariably by smoke.

Fig. 1. Tuyeres in refractory for admittance of over fire air

Many factors influence the required volume. First of all is the required rate of combustion to supply the steam needs of the plant which determines the total rate of heat release per hr. by the fuel. Dividing this total quantity by desirable heat releases per cu. ft. per hr. will give the desired volume. Width of the boiler and its height above furnace floor are specified quite definitely by the boiler design; this leaves but one general dimension to be determined which can readily be done once the heat release is decided upon.

Heat release is limited by the allowable temperature in the furnace and this in turn is governed by furnace wall material, the firing equipment and the fusion temperature of the ash. The limiting temperatures for solid refractory walls are about 2400 deg. F. Higher temperatures may be endured for short periods, but the bricks are liable to become soft and maintenance becomes excessive with continued operation. Temperatures in water cooled furnaces are, of course, lower, but they must be considerably above the ignition temperature of the combustible gases. In slag tap furnaces the temperature must be above the fusion temperature of the ash and where dry ash removal is employed the temperature must be below the fusion point of the ash.

Common practice would indicate that furnaces with solid refractory walls are designed for heat releases between 12,000 and 35,000 B.t.u. per cu. ft. per hr., while those with water walls vary between 20,000 and 84,000 B.t.u., the highest releases being obtained in slag tap pulverized coal furnaces.

Ash Removal

Once the combustible matter has been burned out of the fuel any solid refuse remaining must not be allowed to accumulate to the point where it interferes with combustion or the flow of heat to the water. Of necessity, any type of coal burning equipment that does not continuously discharge ash must allow a certain amount of accumulation. This is the case with hand-fired grates and certain types of stokers. In these cases the ash is either

drawn out of the furnace through the firing door or dropped into the ash pit for removal. Cleaning periods must be so selected as not to interrupt service.

On traveling grate stokers, the combustion is progressive with the ash going over the end of the stoker to the ash pit for removal without any interruption in boiler service. In some designs water backs have been used to prevent unburned fuel from discharging to the ash pit by being placed so close to the grate that lumps of coke are held back until they are reduced in size. Careful handling of forced draft with these stokers is essential to prevent the light ash at the rear of the stoker from being blown into the furnace space, to be carried through the gas passages as fly ash, or on to the walls or the hottest portion of the fuel bed to collect as slag or clinkers.

Although early designs of underfeed stokers offered some difficulty in the removal of ash, due to the fact that the combustion is progressively upward from the bottom of the fuel bed with the ash at the top, recently designed furnaces maintain the ash temperatures at a point below fusion, thus permitting them to gravitate to the ash pit without serious clinkering taking place. In common designs the combustion of the fuel is completed in a clinker grinder pit or on an overfeed section at the rear of the stoker. Single retort stokers have side plates where combustion is completed. Ash is removed from these plates either by dumping them or hoeing the refuse out of the furnace through the front doors.

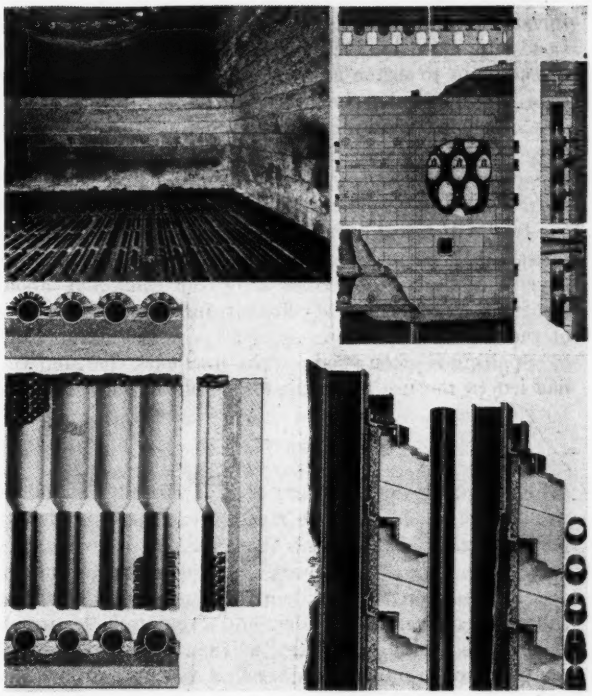


Fig. 2. Typical solid refractory, air-cooled and water-cooled furnaces

Pulverized Coal Ash

Two methods of removing ash from pulverized coal fired furnaces are in common use. By what is known as the dry method the ash falls from the furnace space through a screen of water tubes, that keeps the ash below the fusing temperature, to an ash pit from which it is discharged to conveying equipment for disposal. This method requires a comparatively cool furnace. The other acceptable method is to maintain a furnace temperature so high that the ash remains in a molten state at the bottom of the furnace from which it is drawn off continuously or at intervals, pouring into a stream of cold water that shatters it into particles of fine gravel size and conveys it to the ash dump.

Where the furnace temperatures are so high as to fuse the ash, particles of fine ash suspended in the furnace gases find lodgment on the side walls or on the boiler tubes first passed by the gases. This slag needs special consideration. If stokers are used with solid walls, the slag is likely to give trouble by running down on to the grates and there congealing into clinkers, due to the cooling effect of the combustion air coming in through the grates. To prevent this trouble, some furnaces are designed with air tuyeres in the refractory for a short space above the grates along the side walls. Air admitted here causes the ash to congeal at a distance above the grate and what drips to the grate falls in drops on the fuel bed and is carried away with the ash. Water walls used in pulverized coal furnaces are sometimes left bare for the intentional purpose of congealing slag until a thickness of coating is reached where the rapidity of heat transfer is not sufficient to prevent melting on the inner surface, the slag then runs down the wall to the slag tap bottom. Similar action sometimes takes place in the lowest boiler tubes. To avert trouble here the first two rows of tubes are spaced far enough apart that slag bridges cannot form and as the gases pass these tubes they become cooled below the fusing temperature of the fly ash.

Confining the Heat

With temperatures running at times as high as 3000 deg. F. inside the furnace walls, the problem of preventing the heat, air or gas from being transmitted through to walls to the surrounding atmosphere is not easy of solution. Three general classes of walls are in use: (1) Refractory—solid and air cooled; (2) Water cooled—bare tube, stud tube and refractory block tube; (3) Steam cooled—radiant superheaters and reheaters.

Solid refractory walls are used where the heat release is not over 12,000 to 15,000 B.t.u. per hr. per cu. ft. and great capacity is not required. They are applicable to grate and stoker fired coal burning furnaces, also oil or gas fired boilers. Air cooled walls are used where greater capacities are required, thus permitting a reduction in size of the furnace and an increase in heat release. Although considerably more expensive in first cost, the air cooling cuts down maintenance and by using the heated air for combustion purposes, the heat it picks up is returned to the furnace without loss.

General properties of refractory materials are given in Table I. These materials are used in various combinations in the manufacture of firebrick and special shapes, refractory cements and monolithic materials used for linings are hammered into forms, thus building the walls into a solid, uniform structure. It is customary to build the inner surface of the furnace wall of high temperature refractory that has a fusion temperature of around 3100 deg. F. This is backed up with insulating material and an outside wall of building brick. Good

refractory must be strong, have low shrinkage and deformation, and must resist vapor and slag penetration. Load supported by firebrick should be kept small as the brick begins to soften and give under load at a temperature 500 to 600 deg. below fusion temperature.

Air cooled walls are built with air duct spaces between the lining and the outer wall, the lining usually being supported on steel structural shapes designed to make repair easy. The air thus heated is conducted to the fuel bed or coal burner and used for combustion purposes. In some cases refractory blocks are made into tuyeres and placed in rows along the walls just above the fuel bed to admit over-fire air and create turbulence of the gases.

Spalling is often produced by unequal expansion and has led to the use of expansion joints in some designs.

Water Walls

Furnaces to serve boilers of high capacity would be prohibitive in size if some means were not provided to permit higher heat releases than are possible with only refractory walls. This necessity brought on the use of water tubes along the inside of the furnace walls. These tubes are connected to headers and circulate boiler water, thus by absorbing heat from the furnace they reduce its temperature permitting higher heat release and less furnace volume at the same time protecting the refractory.

The amount of water wall surface and the location of the tubes depends upon the fuel used and the type of burning equipment, the shape of the furnace, the final temperature of the steam and the method of removing the ash. Too little water wall surface limits the rate of combustion, too much will cool the gases and cause incomplete combustion at low loads on the boiler. The customary locations are along the refractory walls in those locations where the heat is most intense and the refractory needs most frequent repair, beneath pulverized coal furnace bottoms, lining clinker grinder pits, facing for the rear walls of underfeed and traveling grate stoker furnaces and even the fuel beds of underfeed stokers.

Table I. Properties of Refractories

Material	Fusion Point F°	Point of Failure Under 50 lb. Per Sq. In. Load	Thermal Conductivity at 1832° F. B.T.U. Per Hr. Per Deg. F per 1"	Specific Heat at 212° F	Resistance to Spalling
Fire Clay	3092	2462-2552	11.3	.199	Good
Silica	3092	2912	12.7	.219	Poor
Magnesia	3929	2696	22.9	.231	Poor
Chrome	3722	2597	16.5	.....	Poor
Bauxite	3245	2462 or more	11.3	.....	Good
Zirconia	4667	2750	Low	.....	.....
Carborundum	4064	Above 3002	67.0	186	Good
Alundum	3722	Above 2822	High	198	Good

Bare tube walls are commonly used where coal is used as fuel, particularly in pulverized form, and the ash is deposited dry in a hopper bottom furnace. Bare tubes are not suitable where they are subject to abrasion but have inherently high heat-absorption capacity.

In slagging furnaces, tubes faced with block are commonly used, they are also applicable at the stoker side walls and at other locations where ash and clinkers grind against the wall. These tubes are faced with closely-fitted cast-iron blocks that protect the tube surface.

Another method of protecting water tubes from abrasion is to weld studs to the tube surface then cover it with plastic refractory. The studs hold the refractory in place, at the same time transmit the heat to the water and keep the refractory from fusing.

Superheater tubes are also arranged along the furnace walls in some designs of boilers, not so much to protect the wall from destructive heat as to accomplish temperature regulation of the superheated steam at varying loads on the boiler. They do, however, tend to lower the temperature of the furnace and shield the wall which they cover.

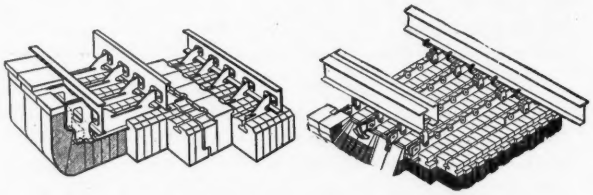


Fig. 3. Suspension arches of typical design

In some recent designs of reheat boilers, reheating of the low pressure steam is done in tubes along the side walls of the furnace. The effect on furnace temperature and refractory is the same as would be expected from water walls.

Some modern boilers served by underfeed stokers and pulverized coal are designed with double furnaces, a dividing wall of vertical water tubes dividing the furnace space into two parts. Such an arrangement not only permits higher heat release, but gives greater flexibility in handling variable loads on the boiler and makes possible, by proper location of superheaters, the control of steam temperature.

One of the more recent furnace designs is that known as the two stage furnace. This has been applied to pulverized fuel furnaces burning bituminous coal with ash that fuses at low temperature. The first stage of combustion takes place in a down fired slag-tap furnace, the furnace gases then pass through openings in a water cooled wall where combustion is completed at lower temperature in furnace space completely water cooled and ash is deposited in dry form in the hopper bottom.

Arches to Aid Combustion

To ignite and completely burn fuel introduced into a furnace requires a certain amount of bottling up and directing of the heat generated, for this purpose arches, usually of the suspended type, are employed. Suspended arches and furnace roofs are built of steel frame work upon which specially shaped refractory is hung. The surface exposed to the furnace heat may be flat or curves, arches may be air cooled by currents back of the refractory or faced with water cooling elements, the object being to secure complete combustion of the required fuel in a furnace of small dimensions without excessive destruction of furnace parts due to high temperature.

Neither pulverized coal burners nor underfeed stokers require ignition arches, but nearly all other types of stokers do require some form of arch to reflect the radiant heat from the hottest portion of the fuel bed to the entering coal, thus driving off the volatile constituents and igniting the coke. The factors entering into the location and size of these arches are determined by the type of

the stoker and the character of the fuel used. Traveling grate stokers are usually provided with both front and rear arches. The front arch protects that section of the fuel bed from the cooling effect of the boiler while the rear arch reflects its heat to the entering coal and prevents extinguishing the combustion of the carbon in the ash as it is carried to the ash pit.

Somewhat similar principles govern the design of arches for all types of gravity feed stokers, the front or ignition arch is usually shorter and the back arch, instead of slightly inclined from horizontal, may be nearly vertical, depending upon the ignition and burning characteristics of the fuel.

Furnaces may further assist combustion by shaping the walls or providing arches so that stratification in the stream of gases is broken up and eddy currents are formed in order to obtain intimate mixture of combustible gases and oxygen. Arches of this type have commonly been used in furnaces serving low-set h.r.t. boilers burning high volatile coal.

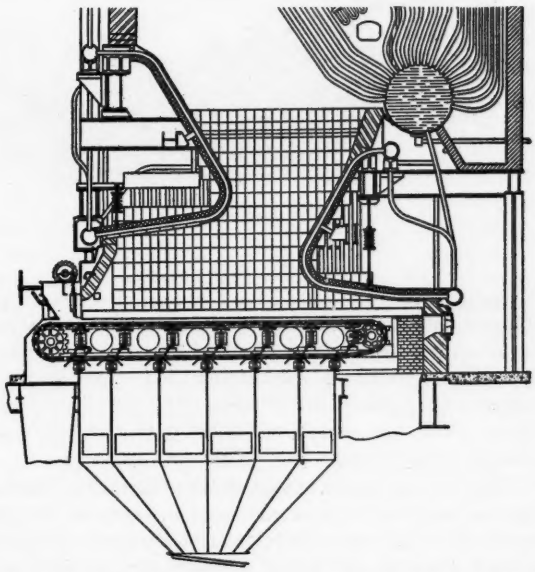


Fig. 4. Water cooled arches over forced draft chain grate stoker

Another function for which furnaces must be designed is directing the inflow of combustion air. With pulverized coal, oil or gaseous fuels all the primary and secondary air necessary for combustion may be supplied at the burner, with solid fuels, however, complete combustion requires that over-fire air must be introduced to supply oxygen for the combustible gases. This air is usually introduced through tuyeres built into the stoker castings along the furnace walls, or through perforated refractory tile a short distance above the fuel bed. Another favored arrangement is by means of jets through the ignition arch which also causes turbulence of the burning gases. Similar results have been secured by jets provided in the bridge wall, their streams being directed across the fuel bed.

It is universally recognized that radiant heat is more easily transferred to the boiler contents than convection heat, so designers of furnaces strive, as far as possible, to place the heating elements where they will be in the direct path of radiant heat from the furnace.

Features of Modern Steam Generators

(Continued from page 21)

tube boilers 10 sq. ft. per boiler hp., one boiler horsepower being equivalent to the evaporation of 34.5 lb. of water from and at 212 deg. F. As higher combustion rates became practicable, accompanied by higher furnace temperatures, and one by one the different heat absorbing elements of the steam generating units were given a specific location in the furnace walls or gas passage, this method of rating boilers has proved to be entirely inadequate and the practice today is to rate boilers on the actual amount of water they will turn into steam per hr. under a given feedwater temperature, total steam temperature and pressure.

The most advantageous proportioning of the heat absorbing elements in a steam generator is still largely a question of opinion. The fact is that what appear to be slight changes in the design or arrangement of elements make such marked differences in performance that heating surface can be considered as only one factor among many in the successful design of boilers. Manufacturers are in possession of data on the performance of their equipment and, by the use of these data gained through experience combined with theory, are able to design units that will meet with extreme accuracy the specified requirements.

How the distribution of heating surface varies with different modern designs is well illustrated in the accompanying Table III. Some of the most important factors influencing heating surface proportions are size of tubes, inclination from the vertical position of tubes carrying water, header connections, fuel used, firing methods, furnace temperatures, steam pressure, steam temperature, load variations, methods of controlling steam temperatures, temperature of feedwater to economizer, and, where reheaters are employed, the temperature and amount of the reheated steam.

Feedwater coming to the unit passes first through the economizer, then to the boiler drum. The circulation then divides part of the water going through the water walls and part through the boiler section, the steam generated rises to the steam drum where separation from water takes place and the steam is passed through the superheater to the turbine. The burning fuel in the furnace is supplied with hot combustion air from the preheater and gives up much of its heat by radiation to the water walls, the hot gases then, by convection, carry the remainder of the heat from the furnace through the labyrinth of tubes, striking first the slag tubes provided to intercept fly ash, causing it to freeze and drop back into the furnace. Next in the path of the gases may be either some of the boiler tubes or the superheater tubes, depending upon the superheat temperature desired, the gases then pass the low temperature boiler tubes and in turn the economizer and the air preheater whence they leave for the fly ash collector, if one is provided, and the stack. The heat transfer takes place, as a rule, on the counter flow principle, so far as this can be arranged, that is, the gases starting hot in the furnaces flow past the heating elements in a general direction opposite to that of the water which starts cold in the economizer. Properly designed units of this sort are capable of absorbing well over 90 per cent of the heat of the fuel.

Much Fire But No Smoke, PLEASE!

That order and others of similar meaning are bringing the process of combustion out of the art class into one of science in which machinery handles the fuel and instruments either control or guide the operation in controlling conditions

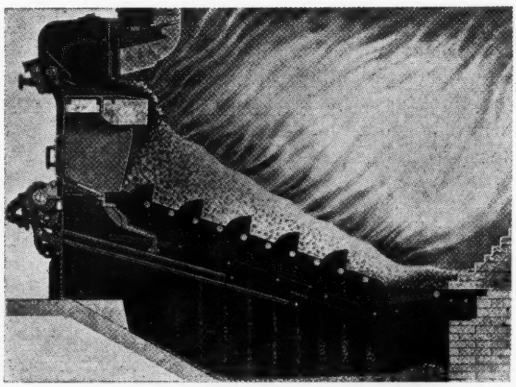


Fig. 2. Front feed inclined grate stoker

WHEN POWER boilers first came into use they were all fired by hand methods. From these the processes of combustion were developed through years of experience until automatic methods with mechanical stokers, pulverized fuel burners, oil and gas burners have now all come into use in the firing of power boilers.

Although hand firing is obsolete in modern plants, there are still many boilers that must depend upon this method of producing steam. Coal is distributed on grates which may be either of the stationary or the dump type, the latter being, of course, far superior in that the cleaning of the fire is made much more convenient by having an arrangement whereby the grate surface is divided into four sections with provision for dumping each section separately.

A more convenient method of hand firing is to deliver the coal to hoppers at the front of the furnace and from these distribute it to a coking plate and by means of hand operated hoe or hand operated pusher grates to distribute the coal down an inclined grate surface with the ash discharging at the rear end of the grate into the ash hopper. Many difficulties arose in the operation of hand fired grates and stokers in that the fuel must be fed at intervals which gave rise to smothering the fire in places, and neglect on the part of the fireman to replenish the fuel at proper intervals, caused a variation in steam pressure and decidedly uneven combustion results.

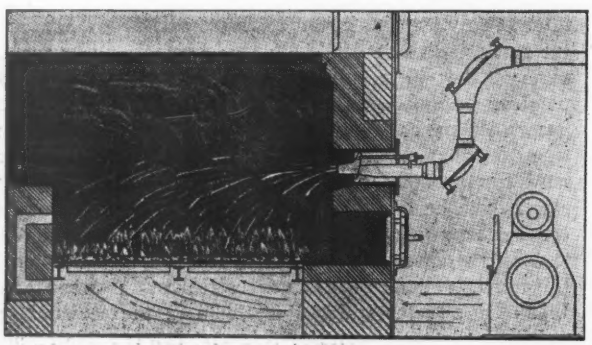


Fig. 1. Pneumatic spreader stoker

Working on somewhat the same principle as hand firing but with continuous and even delivery of the fuel, sprinkler stokers were developed and today hold an important place in the firing of small and medium sized boilers. These stokers are suitable for the use of small size coal and are manufactured in capacities for delivery of as high as 40 lb. per sq. ft. of grate surface serving 1000-hp. boilers. The fuel is delivered to a hopper at the front of the furnace from which it is sprinkled continuously upon the entire grate surface into a furnace that is kept at an even temperature and much of the finer particles of the fuel are ignited and burned in suspension, the remaining larger particles dropping upon the fuel bed burn in what might be termed a soft fuel bed and as the firing is light, this fuel bed is kept thin by rocking the grates so as to remove the ash as it accumulates from the burning fuel bed. One type of sprinkling device uses a rotating paddle which receives the coal from the hopper in small amounts and throws it over the entire fuel bed. The grate used for this purpose is flat or slightly inclined. Another method for distributing the fuel is by pneumatic means. Here the finely crushed coal is placed in a conveniently located hopper, perhaps across the firing aisle from the boiler furnace, and is fed to a pneumatic conveyor that carries the coal through pipes to the front of the furnace where it is spread evenly over the entire bed of the burning fuel by a properly shaped nozzle. With either of these sprinkling

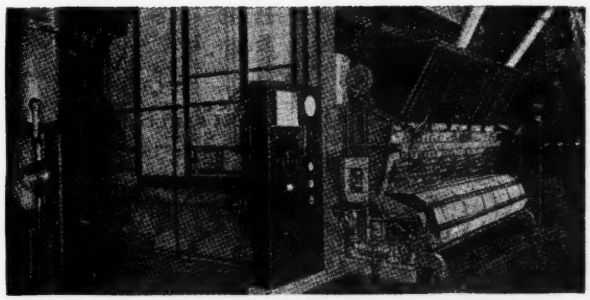


Fig. 4. Traveling grate stoker illustrating how grate bars separate as they turn over front sprockets

stokers natural draft may be used or, in case of necessity, forced draft can be applied to good advantage.

Overfeed Mechanical Stokers

By inclining the grate surface of stokers, it was found that the process of combustion was aided considerably in that the fuel burned progressively from the point of delivery down the inclined grate surface to the ash discharge. Two types of stokers employing this principle are now in use in serving power boilers.

The inclined front over-feed type employs a hopper extending the entire width of the furnace which feeds coal by gravity onto a coking plate. From this plate pusher plates and rocking grates operated by mechanical means continuously work the fuel down the incline to the dump grate where the last of the coke is burned out of the ashes. This plate is dumped at intervals sufficiently frequent to keep accumulations from interfering with the operation of the furnace. As a rule natural draft is employed, although forced draft can be used when it is desired to increase combustion.

Another type of gravity mechanical stoker is the side-feed V-type which employs natural draft and is suitable for bituminous coal having a high fusion point ash as the furnace temperature usually runs high. In this case the furnace is built with a sprung arch as a roof and at each side of this is a coal hopper from which the small size coal is pushed to coking plates. Here it is mixed with preheated air, delivered through the arch plate ducts and when it is pushed to the stationary and moving grates that work the burning fuel to a clinker grinder which discharges to the ash pit. The grate bars in this case are placed in an inclined vertical position and are operated by mechanical means, thus keeping the fine particles of ash from interfering with the passage of air through the grate bars and delivering the clinkers to the clinker grinder. As stated, this type of furnace operates at high temperatures due to the bottled up effect caused by the overhead arch and no opportunity for the radiant heat within the furnace to be absorbed by heating surface of the boiler.

Traveling grates, sometimes classed as an overfeed stoker, include what is known as the chain grate. This consists of an endless chain the entire width of the furnace running between sprockets at the front and the back of the furnace. Progressive combustion takes place here just as with the gravity inclined stoker but without agitation of the fuel bed. The drive in this case may be a steam engine with an adjustable ratchet and dog to propel the chain forward at the speed most desirable for the rate of combustion required. In some cases in place of the ratchet and dog a worm gear is employed which gives smooth forward operation of the chain grate. Other stokers employ variable speed motors through reduction gears.

While working on the same principle, there is a difference in detail between what is known as a chain grate and a traveling grate in that with a chain grate the fuel is burned directly upon the links of the chain, their shape being designed especially for the purpose of admitting air to the kind of fuel burned. The traveling grate, however, is made up of actual grate bars which are attached to the driving chain and enable the designer to suit his stoker more exactly to the kind of fuel he is burning.

Coal is fed to a hopper which extends across the entire width of the furnace front and discharges through an adjustable gate at the front end of the traveling grate. By this means the thickness of the fuel bed is regulated to suit the rate of combustion and the furnace design. As the grate surface moves forward, the coal is first coked, the coke then ignited and burned with the ash discharging over the back end of the stoker into an ash pit.

These stokers are built in sizes from small power boilers up to surfaces of 625 sq. ft. They may be applied for the burning of all kinds of non-caking coal, small size anthracite, coke breeze and almost any other grade of solid fuel used under power boilers. In the operation of these stokers it is important that segregation of the sizes does not take place, for with such a condition portions of the grate will become bare, exposing the unprotected grate bars to destructive heat and giving troubles due to poor distribution of the combustion air. Where operated at low capacities these stokers employ natural draft but where high capacity is necessary, forced draft may be employed to give a high fuel burning rate. Under these conditions zone controlled combustion air is employed. This is introduced between the cross girders, the various zones running parallel to the front of the furnace, each with a damper control, thus providing the correct air pressure for each section of the grate.

Stokers of this type may be secured with either bottom or side admission. Where preheated air is employed, this should not be over 350 deg. since higher temperatures will give difficulty in the operation of the moving parts. It is common practice to design traveling grates with side wall, blast boxes to supply the over-fire where necessary for combustion, particularly when burning fuels with high volatile content.

Stokers of the traveling grate type usually require an ignition arch to shield the green coal from the black

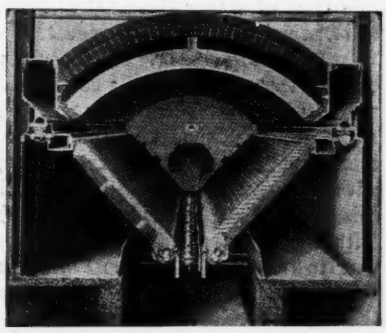


Fig. 3. Side feed stoker with clinker grinder

heating surface of the boiler until the volatile matter has been driven off and the coke ignited. Another arch is required at the rear of the grate which is employed to reflect the radiant heat from the hottest section of the grate to the coking section, thus speeding up ignition. Another feature of this is to secure the complete combustion of the coke in the ash and shield this section of the grate from the intense heat of the furnace, thus preventing destruction of the grate surface where it may be burned. A water-back is commonly employed at the discharge end of a chain grate stoker to protect the refractory from abrasive action of clinker.

The combustion rate of these stokers with anthracite screenings runs at about 35 lb. per sq, ft. per hr., with coke breeze, 40 to 50 lb., and with Illinois coal as high

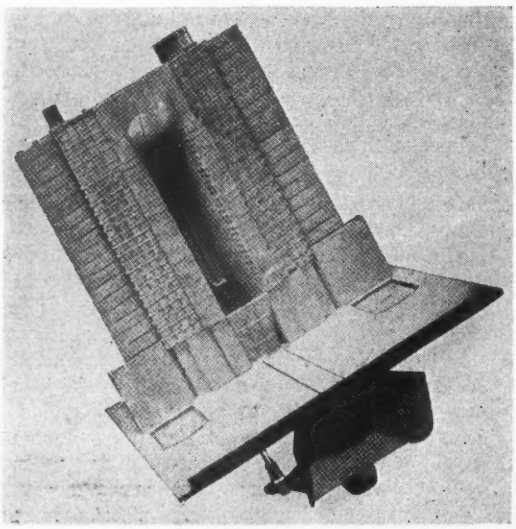


Fig. 5. Top view of single retort underfeed stoker with reciprocating combustion grates

as 60 lb. per sq. ft. per hr. The rate of burning is extremely flexible, being regulated by the thickness of the fuel bed, the speed at which the grate is propelled and the intensity of the forced draft employed. Traveling grate stokers are applicable to all types of boilers.

Underfeed Stokers

Stokers of the underfeed type are characterized by the upward progress of the fuel. The green fuel is pushed into the bottom of a retort either by rams, pusher plates or worm conveyors. It is first coked, then as it rises is supplied with combustion air under pressure and ignites and burns as it progresses upward in the retort. With this type of stoker forced draft must be employed and it is permissible to use preheated air at temperatures from 200 to 400 deg. On the sides of the retorts are tuyeres through which the combustion air is forced into the fuel bed. Over-fire air is supplied through side wall tuyeres either as part of the stoker itself or built into the refractory. In small sizes this type of stoker is built with a single retort placed in a horizontal position. In this case, the ash begins to collect in the retort, progresses with the fuel until at the top of the fuel bed it spills over to the sides onto dump plates where combustion is completed. The dump plates at convenient intervals keeps the fire clean.

In large sizes it is essential to use a number of retorts, characterizing the stoker as a multiple retort type. In this case the retorts are placed on an incline down from the front where the fuel is ignited. Progress through the retort is as explained above except that the ash falls by gravity onto an overfeed section which may be moving grates to work the ash to the clinker grinder pit at the rear or in some cases these grates are stationary but placed at such an angle as to permit the ash to progress by gravity alone.

In capacity, underfeed stokers may be secured in sizes suitable for household furnaces where the operation is of the intermittent type to those suitable for service under the highest capacity boilers now manufactured. Combustion rates employed vary from 25 to 30 lb. per sq. ft. of burning surface per hour for single retort stokers up to as high as 60 lb. with multiple retort type at continuous operation, and even 89 lb. per sq. ft. for short-time periods. Furnace releases are from 20,000 to 30,000 B.t.u. per cu. ft. per hr.

Fuels used in underfeed stokers are usually high volatile coals having high fusion temperature ash. They are driven either by steam pistons, steam engines, electric motors or hydraulic gears. Stokers of this type are flexible in operation, being capable of low rates of combustion as well as high, thus serving well a boiler operated under varying load conditions. Removal of ash is either by dump plates operated at intermittent periods or, in larger installations, by means of clinker grinders that

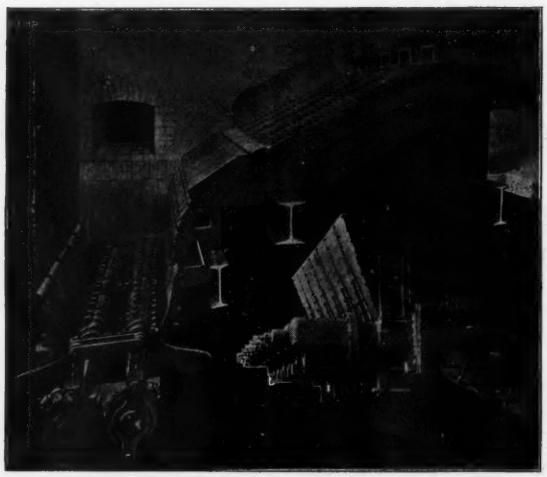


Fig. 6. Multiple retort, inclined-grate underfeed stoker

discharge the ash continuously. As a rule a water back is employed with these stokers which protects the refractory. Recent designs have also included water cooling of the fuel bed itself by means of tubes placed alongside the retorts through which boiler water is circulated. By this means, difficulties common with low fusion temperature ashes have been relieved.

Pulverized Coal Burners

Designers of modern boilers in most cases seem to prefer the burning of fuel in pulverized form under the high capacity, high temperature boilers. Burners of this type are suitable for the use of bituminous coal or bituminous coal with a percentage of anthracite mixed.

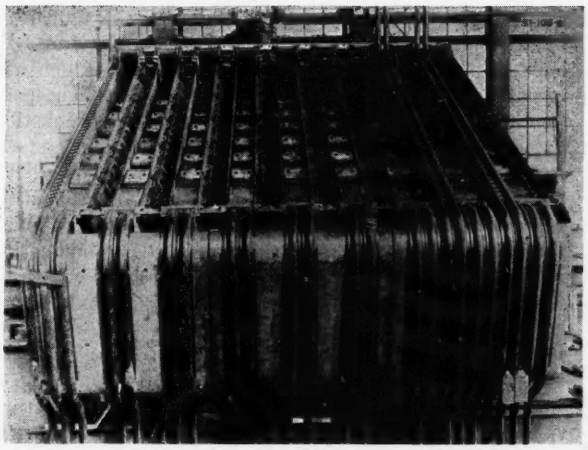


Fig. 7. Shop view of water cooled underfeed stoker under construction

They also operate well with lignite. Other fuels such as coke and petroleum carbon have also been used with success, although the supply of these is limited. Pulverized fuel burners may be placed in the walls or ceiling of furnaces and the number installed depends entirely upon the required capacity of the boiler. They are applicable to any type of boiler but used most extensively with the water-tube type. For horizontal return tubular boilers usually only one burner is required. This is placed in the front of the furnace which extends the full length of the boiler setting in order to give volume in which to burn the fuel.

Pulverized coal burners require primary or carrying air to deliver pulverized coal to the burner nozzle. At this point secondary air is introduced which has an atomizing effect upon the stream of coal and air. This gives the intimate mixture necessary for complete combustion. As a rule preheated air is employed for both primary and secondary supply, the temperature depending upon economic conditions, ranging from 350 to 400 deg. This causes rapid ignition and combustion which are necessary to limit the furnace space. Good combustion required a pulverized fuel burner that will cause turbulence in the furnace. This may be done in several ways. If but one burner is used, common practice is to employ a burner with diffusion vanes which produce what might be called a mushroom flame. Turbulence may also be produced by locating the burners at the four corners of the furnace, directing the discharge in such a way as to effect circular movement of the furnace gases, an arrangement commonly known as tangential. Where

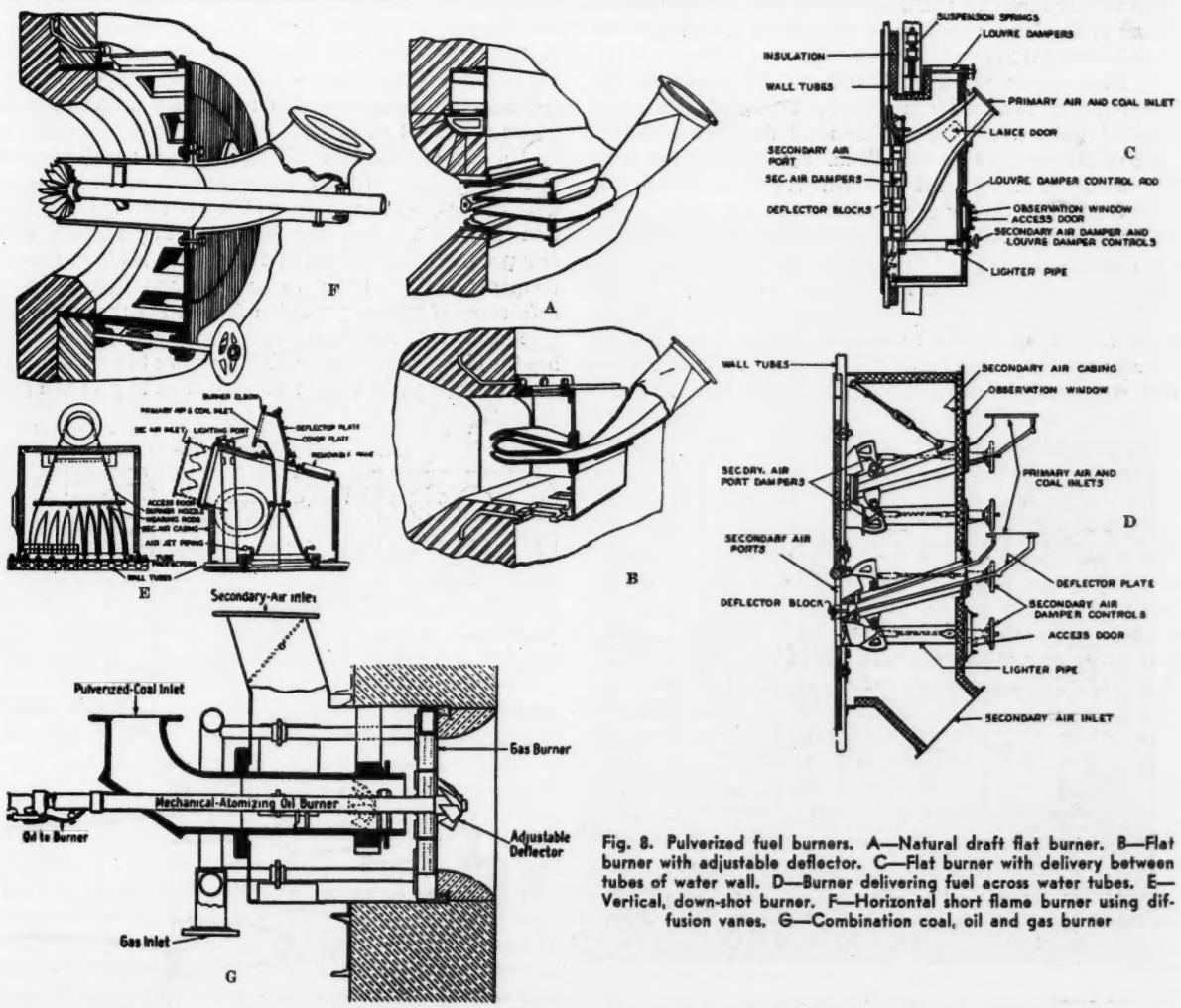


Fig. 8. Pulverized fuel burners. A—Natural draft flat burner. B—Flat burner with adjustable deflector. C—Flat burner with delivery between tubes of water wall. D—Burner delivering fuel across water tubes. E—Vertical, down-shot burner. F—Horizontal short flame burner using diffusion vanes. G—Combination coal, oil and gas burner

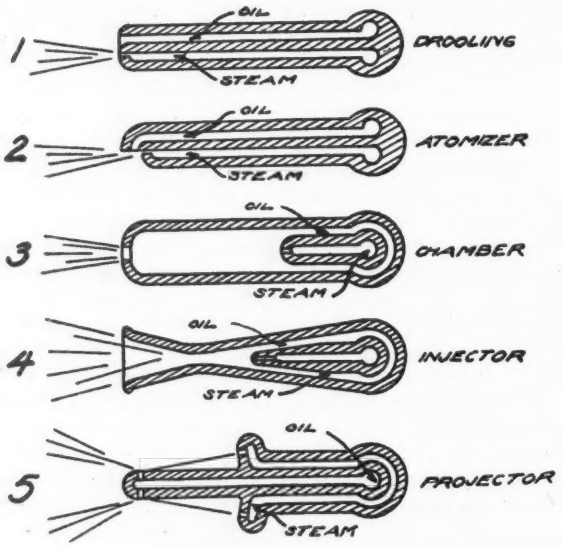


Fig. 9. Illustrating principles of oil atmomizing

firing is done from only one wall of the furnace the burner itself must be depended upon to give turbulence. Another location is in the roof or top arch of the furnace with the burner directing the discharge of the fuel downward, thus giving longer passage to the flow of gases than with the horizontal firing.

Illustrations herewith show types of flat burners employed with refractory walls, also those used with water cooled walls where the burner must deliver coal either across the tubes or between them. Examples of the down fired burner and several turbulent types are also shown.

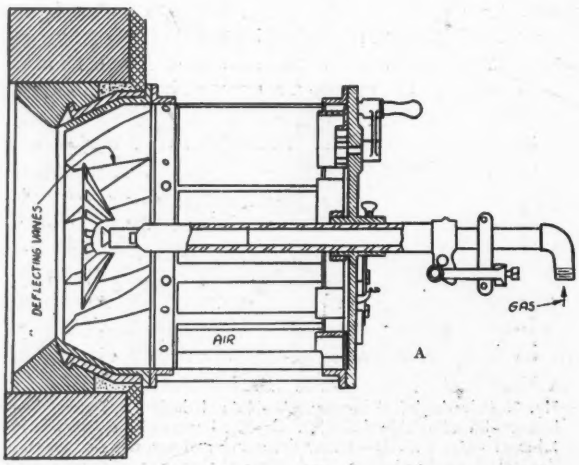
Oil fuel has many advantages over solid types in that conveying to the burner, operation of the burner, supplying of air, simplicity of the furnace necessary and absence of ash make this fuel almost ideal so far as convenience is concerned. Oil is burned not in the vapor form but it must first be gasefied before it units chemically with the oxygen of the air. For this reason the burner must convert the oil into a fine mist or spray which is done either by the use of a steam or air jet or by mechanical means. In either case the oil must be burned in the presence of refractory material which will radiate heat to assist ignition and the combustion space should be large enough to permit complete combustion before the flame is cooled by the boiler heating surface.

One of the functions of the burner is to spread the flame so as to distribute heat uniformly on the heating surface and thus prevent the blow torch effect which would be destructive to the boiler metals. Combustion practice would indicate that it is well to have one cubic foot of combustion space per pound of oil burned per hour. This figure applies to boilers where the furnace draft available is less than 0.1 in. with the resultant velocity of gases through the furnace when running at ratings about 7 ft. per second. With horizontal return tubular boilers which approach the above condition, some authorities figure on 4 ft. of heating surface to a cubic foot of combustion space. For average fuel oils, the amount of air theoretically required varies from 13.8 to 14.8 lb. or from 180 to 200 cu. ft. per lb. of fuel, depending on the temperature of the air and the calorific value of the fuel.

Many oil burning furnaces are designed with the walls and floor air cooled, the air being heated to around 400 deg. F. and used for combustion to increase economy. With proper arrangement of burner and furnace, not over 15 per cent excess air should be necessary. Ten per cent of the combustion air is used at the burners in the atomizing process, the balance coming through other openings judiciously located to furnish combustion air where it is most needed.

Oil burners and their air registers are usually located in the front wall of the furnace, but where oil is used as a supplementary fuel, side wall or even bridge wall location may be the best arrangement. The furnace must also provide sufficient outlet for radiant heat, as furnace temperatures are likely to be high and destructive to refractory if proper provision for cooling the furnace is

Mechanical atomizers are of two types—one system has the oil delivered under high pressure to a small nozzle and through guide vanes so designed as to give the fluid



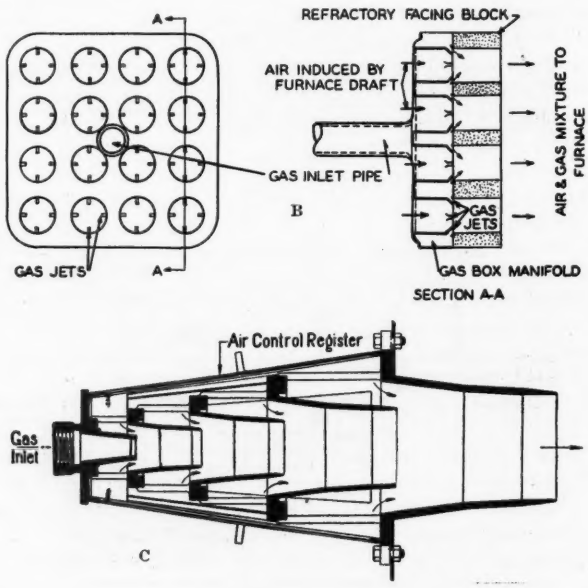


Fig. 10. Types of gas burners. A—Turbulent. B—Multijet. C—Venturi

a rapid swirling motion. A small orifice breaks up the stream into fine particles and the swirling motion spreads the spray. The other type is the centrifugal atomizer which consists of a disk or cup placed just above the floor of the furnace and is rotated at high speed by a motor. not provided. When oil is used as supplementary fuel, ignition arches necessary with certain types of stokers are likely to undergo rapid deterioration if oil burning is employed without taking the shape of the furnace into consideration.

Heat releases with both mechanical and steam atomizing burners have reached as high as 27,000 B.t.u. per cu. ft. of furnace space per hour in water cooled furnaces; with air cooled walls, 54,000 B.t.u. for mechanical and 35,000 B.t.u. for steam atomizing and with solid refractory wall furnaces, 52,000 for mechanical and 32,000 for steam atomizing burners would appear to be maximum releases.

For the burning of oil, the ideal furnace would have the following characteristics: (1) Sufficient furnace volume for total oil burned at the desired rate of combustion. (2) The maximum of refractory surface to assist in maintaining a high furnace temperature. (3) Increase of cross sectional area of the furnace with the expansion of gases. (4) Minimum area close to the flame of cooling surfaces which tend to reduce the furnace temperature. (5) Walls and tubes sufficiently removed from the atomizers to permit of complete combustion of oil before coming in contact with it, to prevent oil striking the wall opposite the burner before burning is completed a minimum distance of 8 ft. should be allowed; a greater distance is advisable. (6) A minimum of infiltration of air except through the air cooling registers provided for the purpose. (7) Exit of incandescent gases of completed combustion from the furnace at a maximum distance from the atomizers.

Fundamental features of several types of oil jet burners are shown in the illustration, these being suitable for either air or steam atomizing. The oil is heated to a thin consistency by means of steam or preheated air used for atomizing, and as it leaves the burner is struck by a blast of steam or air which vaporizes it and spreads it in a fan shape into the hot furnace which ignites it immediately.

The oil is allowed to flow out on the surface of the disk through a hollow shaft, the rotation of the plate throws the oil out into the furnace in a thin sheet of fine spray, combustion taking place in the ring around the disk.

Ignition of fuel gas takes place instantly when the gas is brought to the ignition temperature in the presence of air and the function of a gas burner is simply that of discharging the gas into a heated furnace and mixing it with the proper amount of air to supply oxygen for complete combustion. The function of the furnace is, therefore, mainly to transfer heat from the burning gas to the heating surface, inasmuch as there is no ash to be removed from the furnace. Gas burners have been so perfected that only 5 or 6 per cent of excess air is needed to insure complete combustion, hence a volume of 0.2 cu. ft. per sq. ft. of heating surface or 2 cu. ft. per rated boiler horsepower is adequate furnace capacity. One burner of not over 8 in. diameter, using gas of 1000 to 1300 B.t.u. per cu. ft., will supply a maximum of 30 developed horsepower. Velocity through the burner is about 700 ft. per second at a pressure of 2 to 8 ounces at the burner. Main gas pressure is 25 to 30 lb., reduced in burner mains to 4 to 7 lb. and further reduced at the burner.

In the illustrations are shown typical burners for fuel gas with the air supplied around the outside through deflecting vanes to give a whirling motion and turbulence. Another type illustrated is known as the multi-jet burner having a field of application where the gas pressure is low and natural draft is depended upon to furnish combustion air. When operated at normal rating, these burners give complete and efficient combustion in a comparatively small volume. At other ratings, however, the air-gas ratio for proper combustion is difficult to maintain and the furnace volume required becomes excessive at high rates. The Venturi tube burner also illustrated employs the principle of pre-mixing air and gas and offers great flexibility of load with efficient combustion throughout a wide range of capacity and high heat release in furnace volume. With these burners, gas pressure as well as combustion air pressure may be varied to suit load conditions. Forced, induced or natural draft may be employed and preheated air is used in some plants.

The principles of combustion which govern the burning of pulverized fuel, oil and gas are so nearly identical that a furnace designed for pulverized fuel may be used as highly efficient oil and gas burning furnaces. This has brought about the development of combination burners, one of which is illustrated herewith. This burner may be shifted from one fuel to another by merely making adjustments of valves and controls. Any combination of pulverized coal, gas or oil may be employed in these burners which are installed in plants where market price fluctuations warrant the installation of equipment that will permit a quick change from one fuel to another.

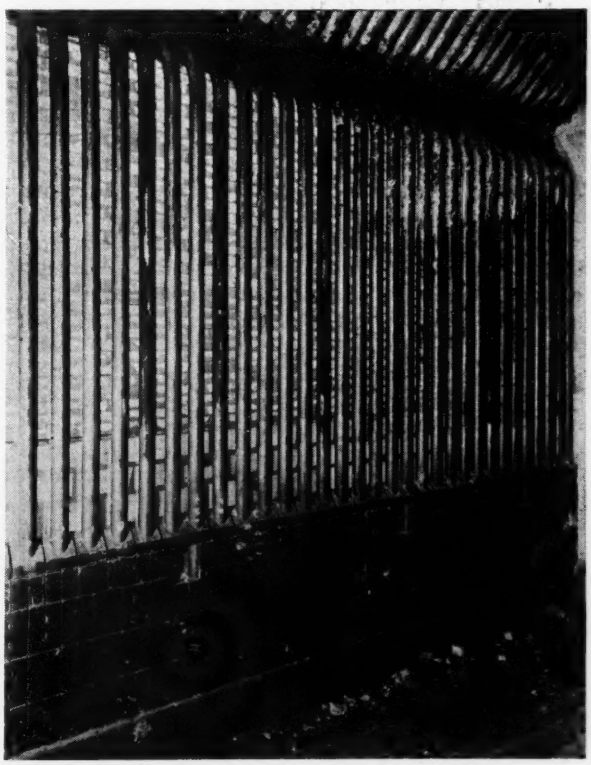


Fig. 11. Rear water wall used in an underfeed stoker fired furnace

Modern steam generators allow only a small fraction of the heat generated in the furnace to escape by way of the chimney; the reclaiming elements, oddly enough the last to contact the hot gasses, are the agents that prepare the air and water for their courses through the boiler

Economizers and Air Preheaters Turn Waste Into Profit

WHEN it is realized that one per cent of the fuel bill is saved for every 30 deg. F. fall in stack temperature due to some heat recovery equipment, it is easily appreciated the bearing which the final temperature has on the financial return of a plant and that a very considerable expenditure may be shown to be justified for any means for reducing this temperature to certain limits. These limits, so far as the economizer and air preheater are concerned, depend on the initial cost of this equipment, the maintenance charges on it, the price of fuel and the load factor of the plant, but there are few large power stations where it does not pay to reduce the gases to 250 deg. F.

Economizers and air preheaters are heat reclaiming devices, that is, they use heat rejected by the boiler to the flue gas as it passes through the economizer and air preheater for steam generating purposes. The temperature of the flue gas as it leaves the boiler ranges from 50 to 100 deg. higher than the saturated steam temperature generated by the boiler itself. In plants that operate at around 1400 lb. pressure, the saturated steam temperature is in the neighborhood of 580 deg. so that in installations of this class considerable heat can be reclaimed by the use of economizers and air preheaters.

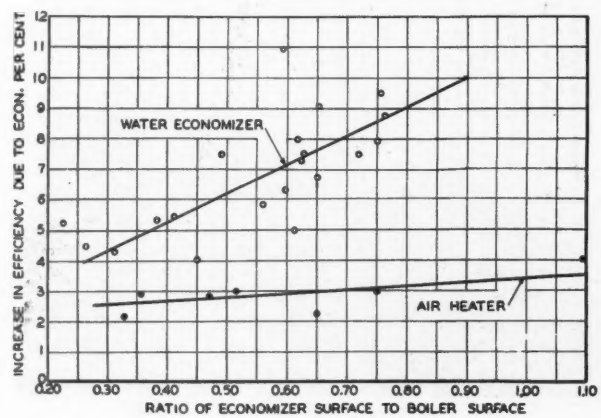


Fig. 1. Heat recovery variation with economizer surface

In the usual arrangement, the gases pass first through the economizer heating the water on its way from the feedwater heaters to the boiler. The temperature at which the gases leave the economizer depends to a great extent upon the steam cycle employed in the plant, since feedwater is in modern practice heated in stages by steam bled from the turbines, the higher the bled steam temperature, that is, the more stages of bleeding which are employed, the higher will be the inlet temperature to the economizer and the higher will be the temperature of the gases leaving this economizer.

Economizer a Low Temperature Boiler

In modern practice the function of the economizer is little different from that of the boiler tubes except that the heat recovered is at lower temperature than in the boiler itself. The function of the original economizers has been largely taken over by the air preheaters, in that the air preheater is operated at lower temperatures today than is the economizer and the economizer has stepped up in temperature so that it now recovers high temperature heat from high pressure boilers. Heat transfer compares favorably with boilers on a unit basis of temperature difference. Many steam generating units in operation today have greater heating surface in the economizer than they do in all the rest of the water and steam heating elements combined, ranging in notable installations as high as 67.5 per cent. Heat transfer from the gases to the water in the economizers is by convection, the usual counter-flow principle being employed throughout.

Economizers are flexible in construction and location, making the control of the heating surface and gas proportioning easily possible.

In Fig. 1 is shown the increase in economy due to increase in ratio of economizer surface to boiler surface. This is a straight line ratio and may be expressed by the formula:

$$(t_2 - t_1) \div (T_1 - T_2) = C\ (W \div w)$$

where t_1 and t_2 are the initial and final temperatures of the water; T_1 and T_2 the initial and final temperatures of the flue gas; w is the weight of the water; W the weight

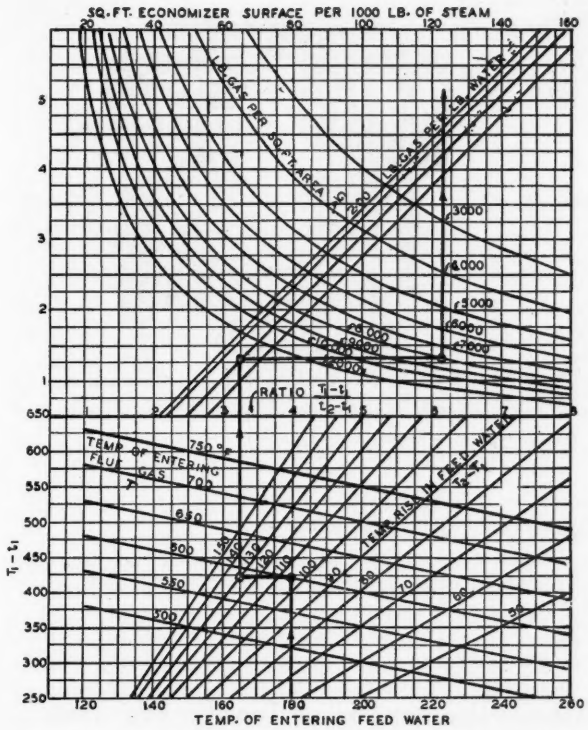


Fig. 2. Graphic chart for determining economizer surface required

of the flue gas passing through the economizer per hour, and C is the mean specific heat of flue gas which for usual calculations may be taken as constant at 0.245 B.t.u. per lb. per deg. F.

Figure 2 is a chart designed for calculating economizer surface on the basis of the formula given.

Materials

Originally economizers were made of cast iron, principally because of the low cost and resistance to corrosion. Under the conditions of operation until a few years ago the inlet temperature of the water was low, causing condensation of moisture in the flue gases on the outside surface of the tubes. This moisture combined with sulphurous gases from coals commonly used in the generation of steam readily attacked metallic surfaces and caused rapid corrosion on the exterior of the economizer parts. There was also the destructive effect of the oxygen in the boiler feedwater which caused internal corrosion. This corrosion problem was met as stated above by the use of cast iron for practically all parts of the economizer. As pressures and temperatures under which the economizers could economically be operated increased, it was found necessary to go to steel tubes in order to withstand the pressures and as a consequence the exit gas temperature was necessarily raised in order to prevent condensation of moisture in flue gases and subsequent corrosion and internal corrosion was inhibited by removing the oxygen from the feedwater. Steel tubes used in economizers are sometimes coated with lead or in some designs covered with cast-iron fins which not only protect the surface but also extend the heating surface, thus reducing the size of the entire economizer unit.

Fig. 3. Steel economizer tubes with cast-iron rings

A common form of economizer using steel tubes of from 2½ to 3 in. in diameter has the tube ends rolled into headers. Feedwater is fed to one end of the lower header and distributed to each of the parallel circuits. The tubes pass back and forth through the gas passage, the bends being usually made of forged steel and carefully machined to receive the tube ends. The use of gaskets is necessary where the tube ends bear against the female joint of the return bend and these are made of soft material, capable of withstanding the temperatures and pressures to which they are subjected.

Location

Economizers are usually encased in removable steel plate panels which are insulated, making it unnecessary to remove the whole side to obtain access to certain tubes. Beneath the economizer element it is necessary to provide soot hoppers when there is a reversal of gas passage in order to collect the soot carried over from the boiler. It is common also to provide soot blowers to dust the tubes when they have become fouled.

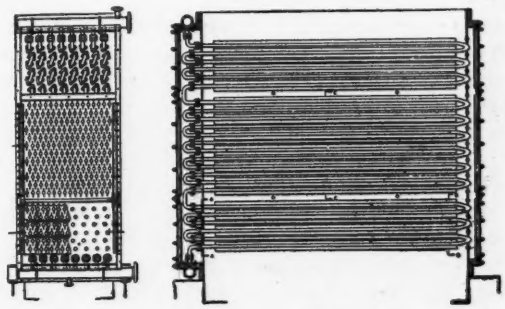


Fig. 4. Steel tube economizer using return bends to connect loops

In recent years the location of the economizer has been changed from the breeching position where frequently it served a whole battery of boilers to a location within the setting, making it really a part of the boiler design. Such economizer sections of boilers receive the feedwater in an upper drum from which it descends through the tubes to the bottom drum of the steaming section of the boiler. Many of these economizers are of the steaming type, having a temperature so high that they actually generate steam and in this case the upper drum of the economizer is connected to the steam drum of the boiler so that any steam accumulation in the economizer is passed over to the boiler proper, the only difference between the economizer section and the boiler section being that there is no water flowing from the boiler tubes into the economizer. In some installations high and low pressure boiler feed pumps are used, this arrangement being employed in order to reduce the pressure on the economizer, thus reducing the initial cost of this equipment.

As stated above, the function of the air preheater is to recover all possible heat from the flue gases before they pass to the chimney. The air heated in this way is used

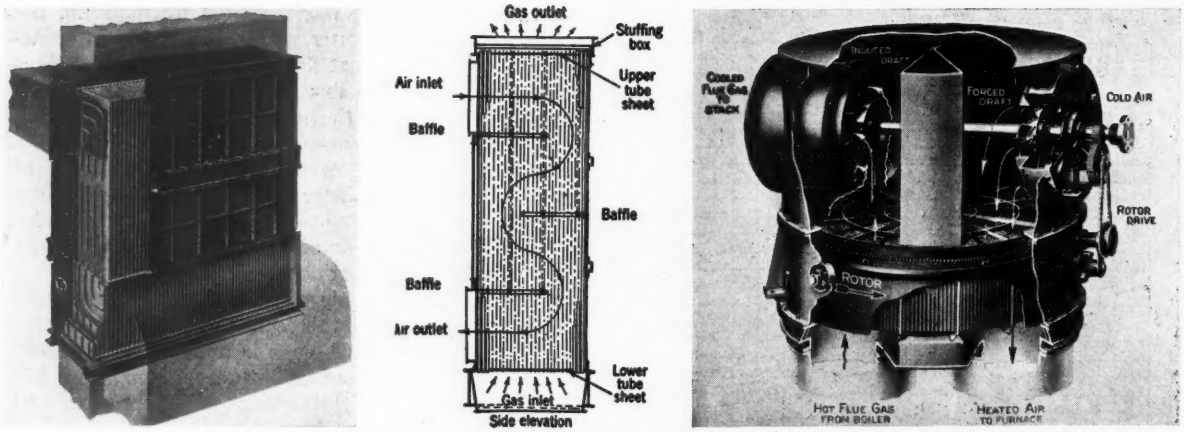


Fig. 5. Air preheaters: A—Plate type. B—Tubular type. C—Regenerative type

to improve combustion in the furnace, thus aiding in bringing the initial temperature of fuel to the ignition point and by this means reducing the size of the furnace necessary. The temperature of the preheated air depends of course upon the flue gas temperature and the firing methods. For stokers the top limit of preheated air is between 200 and 300 deg. F. With pulverized coal, oil or gas, the limit of the temperature is governed by economic conditions of the heat cycle employed, although usually this does not exceed 400 deg. F.

As to construction and principle of operation, air preheaters may be classified under three types, namely: tubular, plate and regenerative. The tubular air heater, which is typical in modern practice, consists of steel tubes, 9 to 30 ft. in height, 4½ and 3½ in. in diameter and 10 to 12 B.w.g. gage thickness, set vertically and rolled into top and bottom tube sheets. The air is conducted over the surface of these tubes by means of baffles in such a way as to secure a counterflow with the flue gases which pass through the inside of the tubes. In installing these units, panels of sheet steel are usually provided on one side of the air heater and made removable so that a tube can be reached, cut out and withdrawn without difficulty. A soot hopper is usually installed below the entrance to the heater which is an aid in reducing the accumulation of dust in the unit.

The plate type air heater consists of plates with the air on one side and the gas on the other. These are arranged in parallel ducts and heat is transferred by conduction from the gas passage to the air passage, the counterflow principle of heat transfer being employed. Air is forced into the several envelopes at the top of the heater and flows in a path at right angles to the gas flow across the gas heating surface usually four times in all. Each envelope has the edges sealed against gas leakage by welding and is readily removable for access and cleaning.

In the third type of air preheater, known as the regenerative type, a rotor is driven by a motor through a reducing gear set, the rotor nominally operating at 3 r.p.m. and requiring approximately 1½ hp. The rotor elements are plates with large corrugations, set between undulated sheets, the undulations being set crosswise with respect to the corrugations. In normal operations the gas from the boiler passes up across the gas side of the rotor heating the plate elements. As the rotor revolves, this heated section passes into the air zone and delivers its heat to the cooling air.

It has been roughly calculated that one inch in height of the regenerative heater is equivalent to one foot of the tubular or plate type unit.

Steel in Use Tops Billion Tons for First Time

THE TOTAL TONNAGE of steel in use in this country, in all forms, has topped the one billion ton mark for the first time in history, according to the American Iron and Steel Institute. The total represents an average of 17,800 lb. in use for every person in the country.

If all the steel now in use were to be sold as scrap at present prices its value would approximate $18,500,000,000, or a sum greater than the entire stock of money, including stocks of gold and silver bullion, and currency in circulation, in the United States. Several times that amount of money would be required to replace the nation's stock of steel with new steel.

About 954,000,000 tons of steel were in use during 1935, equivalent to about 17,000 lb. per capita. The increase in 1936 represents not only the production of steel ingots during the year, but also reflects the great tonnages of steel still in use that were put into "permanent" services, such as bridges, buildings and pipe lines, during the early years of the century. In addition, the life of steel is becoming increasingly longer as a result of progress in manufacturing, fabricating and preserving. Because of the longer life, the tonnage of steel taken out of service last year was less than in preceding years.

The estimated tonnage of steel in use includes the weight of the steel in skyscraper skeletons, dams, railroad trains and such other massive steel-built structures, and likewise includes the amount of steel in automobiles, paper clips, carving knives and the multitude of other uses for steel.

In 1900 about 2600 lb. of steel were in use per capita in this country, and during the succeeding thirty years the tonnage in use increased steadily at the rate of about 440 lb. per capita per year, amounting to 8,100 lb. per person in 1915, and 15,400 lb. in 1929.

Superheaters and Reheaters put the finishing touch on the quality of steam used for power purposes; they require exacting control of temperature to prevent destruction of metal

No Watered Stock Here

IN THE OPERATION of steam boilers, the steam coming directly from the boiler drum contains from 2 to 5 per cent moisture as a rule, and such steam used for power generating purposes causes condensation to take place early in the expansion stage of the cycle and also carries with it impurities precipitated by the water in the boiler. To overcome these objections additional heating tubes are almost invariably used in the design of boilers furnishing steam to prime mover equipment.

Wet steam is difficult to cope with in the generation of power, but the real value of eliminating moisture by superheating is the effect on the cycle and proved prime mover efficiency. There are, of course, a number of factors which enter into this benefit derived from superheating the steam, but in general figures the use of 100 deg. F. in superheat instead of saturated steam will save from 20 to 30 per cent of the steam in a direct acting pump, from 18 to 20 per cent in a simple engine, from 14 to 16 per cent in a compound engine, from 12 to 15 per cent in a triple expansion engine, and for turbines the reduction of steam consumption is about 1 per cent for each 10 deg. of superheat. This saving is due in part to the increase in the volume of the steam, but mostly because absence of moisture decreases the friction losses. Where moisture is present in the steam, erosion of turbine blades takes place very rapidly and there is liable to be considerable deposit of scale on the turbine blades, causing a rapid reduction in efficiency of operation and frequent washing of the turbine blades to remove this scale.

Transfer of heat from the gases to the superheater compares on a unit basis very favorably with that to the boiler heating surface and ranges from 5000 to 10,000 B.t.u. per sq. ft. per hr. From an efficiency standpoint, therefore, there is little effect on the boiler having the superheater as an element in the design.

As to the method of heat transmission, superheaters as employed in present day practice may be classified as either the convection or radiant heat type. Convection superheaters were the first to be used, the principle employed being the same as the absorption of heat by water in boiler generating tubes from the gases sweeping over them. As used today, the furnace gases sweep first over boiler tubes, then over superheating tubes which raise the temperature of the steam, at practically constant pressure, to a final temperature which has a relation to the exit gas temperature leaving the superheater section, the quantity of gas flowing and the velocity of flow of both gas and steam. The location of convection superheaters in modern design of water-tube boilers may be described as overdeck, interdeck and intertube. The location in the boiler being that which will give to the steam the desired amount of superheat required by the cycle employed in the plant. What is designated as the overdeck location of the superheater is in the space between the first and second passes of the boiler. With such an arrangement the inlet and outlet headers may be run through the boiler side wall section or located above the boiler roof.

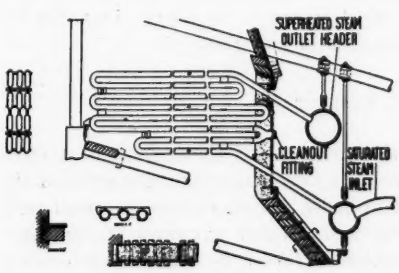


Fig. 1. Multiple-loop superheater showing location of headers and supporting methods

As steam pressures and temperatures became higher, it was found that this location did not always give the required high temperature desired and the boiler was so designed as to give space above the first few rows of boiler tubes for the location of the superheater. Superheaters designed for this location are called interdeck type. In this case several boiler generating tubes are omitted between the upper and lower generating tubes for the full width of the boiler, thus making room for the superheating tubes. With this type two headers are normally used, one header connected to the wet steam being supplied by the outlet boiler drum and the second header acting as a superheated steam-supply header. These headers are suspended all the way across the furnace width and penetrate the boiler masonry at the inlet and outlet ends. Between these headers suitably spaced superheater tubes are connected, each tube usually being looped back and forth several times, the connection varying largely with the different ideas of the designing engineer. Some designs do away entirely with the wet steam header by having the inlet end of the tube elements rolled into the boiler steam drum.

Intertube superheaters are arranged with tube elements so spaced that they may be inserted between the boiler tubes, headers being located in an open space in the boiler setting which permits this arrangement. In order to obtain the necessary initial furnace temperature, the tube elements are customarily located in the first pass of the boiler and in many cases it is found desirable to locate the inlet and outlet headers on steel supports above the boiler roof or on top of one of the boiler drums for rigid support, thus bringing them entirely outside the boiler setting.

Transfer of the heat from the furnace gases to the

steam within the superheater may be either on the parallel principle in which the general direction of flow of steam is the same as that of the flow of the gases. This has the advantage that the hottest gases contact the coolest portion of the superheater and in this way relieves the temperature strain to some extent from the superheater elements. In other designs, the counterflow principle of heat transfer is employed in which the general direction of the steam flow through the superheater is in the opposite direction from that of the hot furnace gases. This type is usually employed where extremely high temperatures from the convection type superheaters is required.

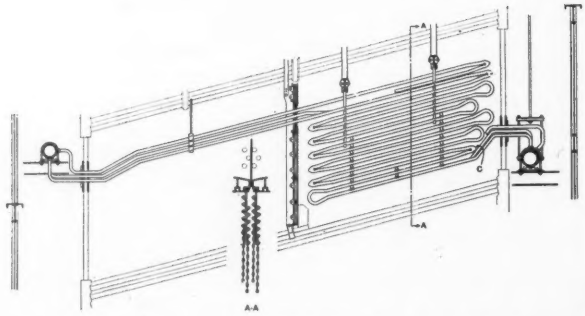


Fig. 2. Interdeck superheater with headers located outside the gas passage

Superheaters commonly used in connection with horizontal return tubular boilers are of two types. One of these is simply strapped around the boiler without changing the setting or arch, so located it absorbs both convection and radiant heat to give the desired flat characteristic temperature to the steam. In another type the superheater elements are hung from the rear arch. This type also receives radiant and convection heat.

Ideal requirements of superheaters as given by Hirshfeld and Barnard are as follows: 1. Perfect freedom of expansion. 2. Ability to withstand high temperatures, high pressure and sudden changes of temperature. 3. Non exposure of joints to the hot gases. 4. Access for cleaning internally and externally. 5. Means for adjusting the superheat to the desired temperature. 6. Automatic control of the desired temperature. 7. Provision in some cases for flooding the apparatus with water and for draining it. 8. Occupation of small space. 9. Low first cost. 10. Small expense for operation and maintenance. 11. Low pressure drop.

Superheater Materials

The materials used in the construction of superheaters depends upon the exact requirements under which the superheater must operate. The temperature strains under which superheaters must operate are the highest of any of the elements in the boiler design, ranging in some instances as much as 200 deg. above the saturation point of the steam and in the large steam generating units now in use the highest temperature of the steam ranges in the neighborhood of about 950 deg., although where lower pressures are employed temperatures have been used as high as 1000 deg. In installations of this character alloy steels must be used, the following being the practice of one company: For steam temperatures of 825 deg. low carbon (0.15 C) steel; for 850 deg. F. medium carbon (0.40 C) steel; for 950 deg. low carbon steel calorized; for 1000 deg. F. medium carbon steel calorized; for 1050 to 1200 deg. F. 18 and 8 alloys. Metal temperatures range from 50 to 75 deg. F. higher than steam temperatures. Inasmuch as alloy steels are much more expensive than the regular steels the higher temperature installations sometimes use two section heaters where the first bend is carbon steel and the second alloy.

Tubes used in the construction of superheaters may be either smooth or provided with extended surface such as cast-iron fins which not only protect the tubes themselves but give greater surface to the element.

Manufacturers have resorted to a variety of methods of fabricating superheater elements. In some cases round or square headers are employed and the tube ends are rolled into these headers, provision being made by openings opposite the tube ends in the headers. In some cases the loops are held in position by spacers and a support is welded onto one of the loops. In another design of superheater studs are secured to the headers between the tube ends and a yoke clamps the tubes at each end to the headers. The seat in the header is conical and the end of the tube elements are machined spherical, thus causing line contact. The tube elements themselves are made of

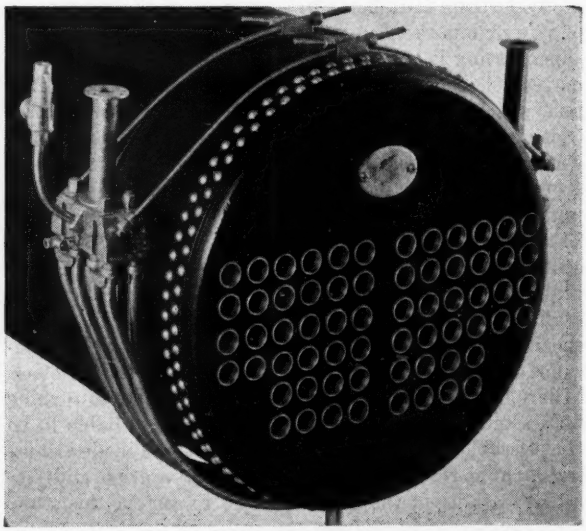


Fig. 3. Superheater installed on h. r. t. boiler

forged steel return bends. A characteristic of one design is that the wall thickness of the return loop at each end is increased on the outer radius for greater strength, also the diameter of the passage around the bend is increased and has a tendency to reduce the friction pressure drop. Superheater headers used for boilers operating at low and medium pressures are made of extra strong open hearth steel pipe with bar reinforcement at the point of entrance to each tube. For high pressures the superheater header is made eccentric with the connections on the diameter where greatest thickness occurs.

Radiant Heaters

Superheaters that receive strictly radiant heat from the furnace are usually placed along the side walls of the furnace, the headers being placed outside the wall with the tubes either rolled into them or connected by joints as is done with the convection type. The exact location

and arrangement of these in the boiler furnace is largely a matter of opinion with the designer and various methods are employed to obtain the desired characteristics from these superheaters. Steam heated in the convection type of superheater rises in temperature as the rate of steam generation in the boiler increases. In the case of radiant superheaters the temperature decreases as the load on the boiler increases. In order to secure operation which will give an even temperature throughout the entire range of

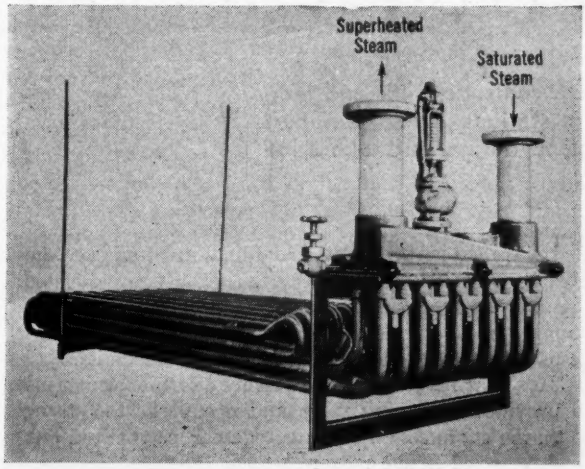


Fig. 4. Superheater unit with tube ends clamped to header

boiler capacity, designers have resorted to a combination of radiant and convection superheaters by placing them in series, the exact temperature characteristic line depending of course upon the proportion of heating surface between the two types of superheaters.

In some cases the superheater tubes are placed without shielding on the furnace wall, in others the tubes are placed staggered with the water tubes protecting the furnace refractory, thus partially shielding the superheater from the intense heat of the furnace, arrangement depending entirely upon the desired final temperature of steam.

Besides this combined radiant and convection method of controlling steam temperatures, engineers have resorted to the use of dampers. To divert the gases from one section of the boiler to another as the load varies, the design of the boiler providing for two or more superheaters so that by changing the amount of gases passing over these elements the final temperature of the steam may be adjusted so as to be practically constant. This is employed in such boilers as the multi-drum V-type where the furnace gases divide and pass through different sections of the setting. Dampers are also used in single pass boilers where the economizer is located in one section and the superheater in another and the flow of gases controlled by dampers to regulate the final temperature. Other designs resort to the use of double furnaces with more superheating surface provided in one than in the other, the result being that controlling the combustion in the furnaces will give a direct control of the final temperature. Another arrangement is to provide a superheat burner placed directly opposite the superheater so that by controlling the combustion from this burner direct control of the final temperature is accomplished. In other designs, desuperheaters are employed either in the outlet from the superheater to the steam header or between two superheaters in series. By this means regulation of the injection of water into the desuperheater controls the final temperature.

In the reheat cycle of power production, high pressure superheated steam from the boiler is first passed through a high pressure turbine from which it exhausts at medium pressure and very little if any superheat. This practically saturated condition of steam is not conducive to the highest efficiency in the operation of low pressure turbines because of the excessive condensate in the low pressure stages of the turbine. To overcome this, steam exhausted from the high pressure turbine is reheated, or in fact superheated, to a temperature that will enable it to expand through the low pressure turbine without excessive moisture being formed. Reheaters are in fact superheaters and are constructed along the same general lines and locations when this reheating is done in the boiler. Pressures of course are not so high as in the initial steam, but temperatures may be brought back nearly to those of the initial steam.

In some installations the expense of piping required to return the steam to the boiler is prohibitive and in these cases live steam reheaters located in the turbine room may be employed or, as has been suggested, though not put into actual practice, a high burning temperature fluid may be used with the reheater located in the turbine room. While the reheat cycle has been used to some extent in modern practice, very few installations in the last few years have been made and in nearly all cases these have been of the gas reheat type wherein the reheat element is placed within the boiler setting following the exit of the gas from the main boiler unit. In one proposed plant, however, it is expected to reheat the steam by means of radiant heat from the furnace, the tubes being placed along the wall of the pulverized fuel furnace. Reheaters of the steam type employ high pressure steam direct from the header of the high pressure boiler, feed into heating tubes in the reheater element with the low pressure steam on the outside of these tubes. The exhaust steam is thus raised in temperature which is limited by the saturation temperature of the live steam from the boiler. Actually temperatures only as high as 500 deg. are usually attained and the thermodynamic gains are reduced as compared with gas reheat. Condensate from these reheaters is of course brought back into the circulation of the high pressure boiler so that little waste of heat in this method of reheating is experienced.

High boiling temperature fluids available for this type of equipment would include mercury, diphenyl and diphenyloxide which have boiling temperatures from 490 deg. to 674 deg. F.

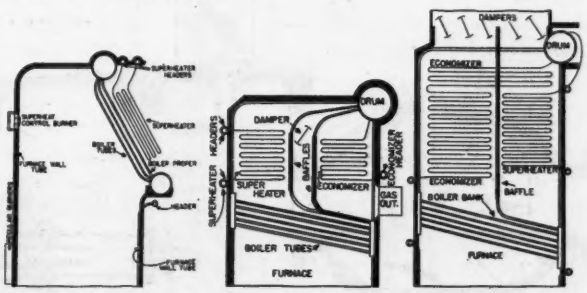


Fig. 5. Methods of controlling superheat temperature. A—Using separate burner. B—Damper to bypass superheater. C—Dampers to divide gases between superheater and economizer

DESUPERHEATING—An Integral Part of the Modern Plant

Fundamentally simple, the accurate control of time and temperature demanded by modern stations makes desuperheating a major problem of plant design and operation

SINCE THE ADVENT of high pressures and high temperatures, desuperheaters have been playing an increasingly important part in the modern power plant by providing protection against excessive temperatures and maintaining continuity of operation under emergency conditions. Desuperheating is usually closely related to, or involved with, pressure reduction. Neither of these involves heat loss beyond radiation but both result in an increase in entropy, a loss of potential power, which makes it advisable to limit their use to emergency service to take care of temporary unbalance in operating conditions, or, to locations where the loss is less costly than the means of eliminating it.

Pressure reduction by throttling, as through a pressure reducing valve, always results in an increase in superheat. At low pressures this is not important, in fact it may be an advantage for a slight superheat results in increased line capacity and decreased radiation losses. As the spread between initial and final pressures becomes greater, especially if the steam is initially superheated, the final superheat soon reaches a value that would endanger low pressure equipment and a desuperheater must be used to keep the temperature within safe limits.

In plants involving high pressure additions it is usual to provide a reducing valve and desuperheater station to tie the old and new sections together, so that old auxiliaries or old prime movers may be operated from the newer and more efficient boilers. In top plants the high pressure turbine is provided with a bypass reducing and desuperheating station which varies somewhat in requirements with the type of plant.

In the early top plants, reheat was involved, the high pressure turbines constituted a comparatively small part of the station capacity, and they exhausted into a constant pressure header in parallel with low pressure boilers. In case the high pressure turbine tripped off the

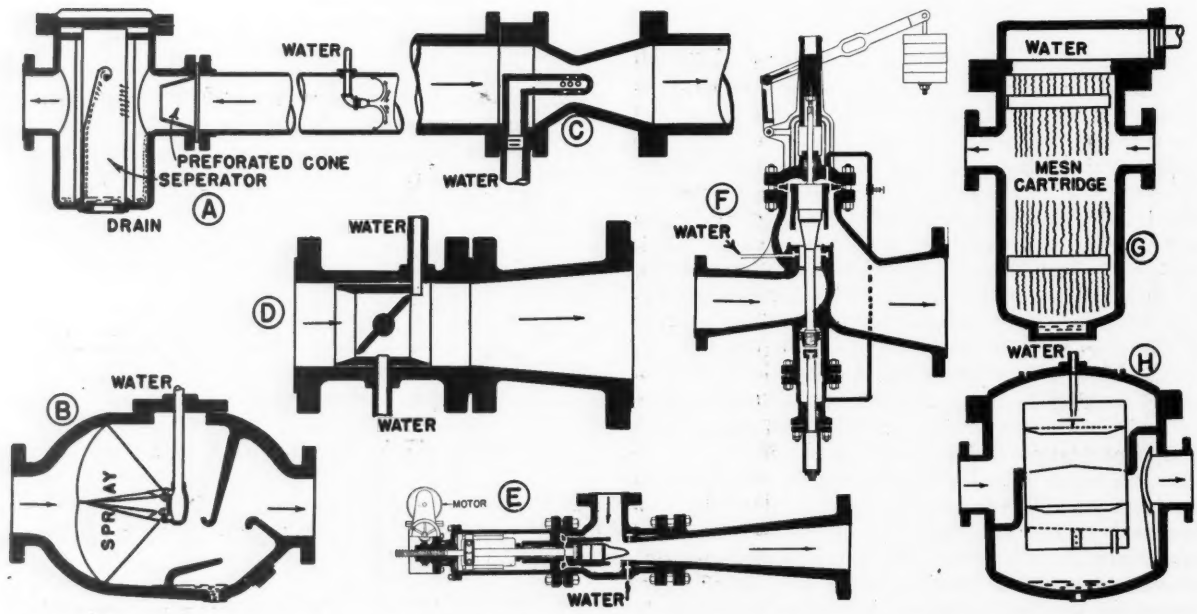


Fig. 1. Various types of desuperheaters in use. Desuperheating is closely involved with pressure reduction and moisture separation and the different

line, the main purpose of the bypass was to protect the reheater against excessive temperatures and prevent the boiler from popping. This had to be done quickly but well within the limits of regular quick acting valves, for the combustion control operated to reduce the firing and both the reheater and boiler had considerable heat capacity.

Demands More Exacting

In the new top plants the problem is much more acute. The top turbines are often an appreciable percentage of the plant capacity and the exhaust may constitute a major portion, or even all, of the steam supply to the low pressure turbines. It is important, therefore, in that case that the low pressure turbine be kept in service if the high pressure turbine trips out. Thus the function of the bypass station changes from comparatively simple matter of protecting the high pressure boiler to one of safeguarding continuity of operation of the low pressure section of the station. This means that the bypass station must be brought into action as rapidly as the turbine throttle closes. In a recent bypass station built to handle over a million pounds of steam per hr., the bypass stop valve is designed to open in ½ sec. The position of the pressure regulation valve corresponds with the position of the steam admission valve to the turbine so that the bypass station is always in a position to take over the pressure regulation without loss of time. Desuperheating is, however, not always tied up with pressure reducing. In modern boilers desuperheaters are used for temperature regulation only, as explained in detail in a later article on steam temperature control.

Fundamentally the question of desuperheating is simple, the real difficult lies in control within the desired limits of time and temperature. The several types of desuperheaters in use are shown by Fig. 1. In some of these the steam is cooled by direct contact with water, in others by contact with tubes or metal surfaces.

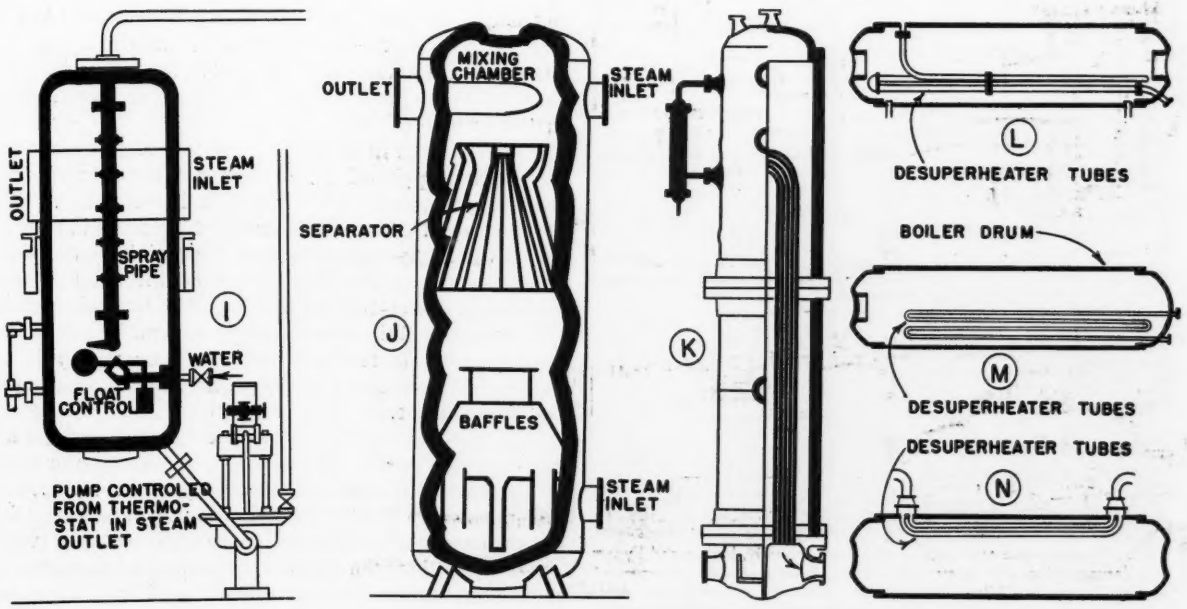
When the steam is to be reduced to saturation temperature, the direct contact type offers a simple solution as an ample supply of water may be used with the excess eliminated by separators, which in Figs. 1A, 1B, 1I and 1J are built integral with the desuperheater. These units involve no pressure reduction beyond the natural pressure loss due to flow and if pressure reduction is involved it must be handled by a separate valve preceding the desuperheater.

It is important of course to get turbulence or proper mixing of the water and steam. A Venturi tube serves as a good mixing medium and several types utilize this principle. Figure 1C shows one type with the spray nozzle at the throat of a Venturi nozzle. This acts as a fixed orifice and involves some pressure drop, but this type is, however, ordinarily preceded by pressure reducing valve controlled from the final pressure. Sometimes both pressure reduction and the spray is combined in a single body as in Figs. 1D, 1E and 1F. The spray is located at the point of highest velocity to get good atomization.

Temperature Control

If a definite superheat must be maintained at the outlet of the desuperheater, the spray water is limited by the action of a throttling valve under the control of a thermostatic element located sufficiently far downstream to allow thorough mixing of the steam and water. As a rule the water used should be as pure as possible, boiler feedwater being the usual source.

The surface evaporative desuperheater as shown by Figs. 1G and 1H is another type of direct contact unit, which it is claimed is less susceptible to carryover of solids because these have a tendency to be left on the wires or rings. In this type the water is distributed over the surface of a metal mesh or rings, upon which the steam impinges. When no carryover can be permitted the closed type of heater as shown by Fig. 1K is used.



parts are sometimes built in one unit. Typical layouts using these units are shown by later figures. The real problem in desuperheating lies in control.

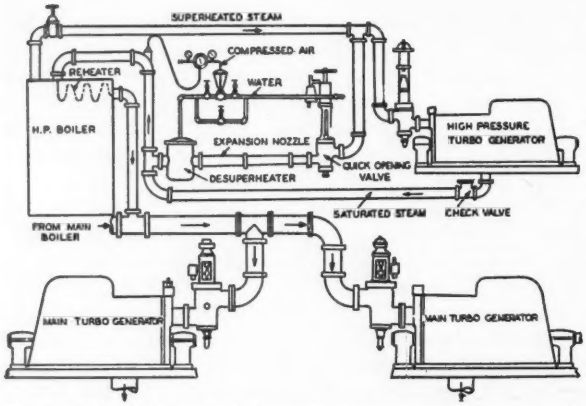


Fig. 2. A simple bypass and desuperheaeer arrangement on an early high pressure topping unit at Lakeside Station. Temperature is regulated by spray under thermostatic control in a unit as shown by Fig. 1H

Application of this type of desuperheater for temperature regulation of superheat from the boiler is shown in detail in an article on steam temperature control elsewhere in this issue. Boiler water is used for cooling and the steam formed is returned direct to the boiler. Accurate temperature regulation is obtained by bypassing a portion of the steam past the desuperheater. Sometimes the desuperheater elements are located directly in the boiler drum as shown by Figs. 1L, 1M and 1N.

Any of the spray or evaporative contact units can be used to give temperature regulation by means of limited water flow under thermostatic control as shown by Fig. 2, an arrangement used on one of the early high pressure stations. A more recent installation is shown by Fig. 3. Here the spray water, supplied from a constant level tank is regulated automatically in the proper proportion by the flow of steam through the Venturi throat. The quick opening stop valve is normally closed but opens automatically if the turbine trips out. The position of the pressure regulating valve depends upon the steam flow through the turbine so it is always in a position to handle the steam flow when the quick opening valve operates, immediately and with a minimum travel.

Another method of temperature regulation used is by means of a bypass as shown by Fig. 4. Here only a portion of the flow is through the desuperheater, through valve D, the balance is bypassed through valve E. The two steam flows are mixed in the top of the desuperheater chamber and leave from the outlet. Temperature control is regulated thermostatically by means of valve E which controls the bypassed portion.

Figure 4 is of further interest in that it shows the control of steam temperature from two sources: That bypassing the turbine from the high pressure steam system through valve A; and that from the turbine exhaust. With high throttle temperatures this last is sometimes important, for with top turbines operating under constant exhaust pressure, the exhaust temperature increases at low loads and in some cases exceeds the safe valve for old equipment. Thus at Springdale the top turbine exhaust temperature varies from 622 deg. F. at full load

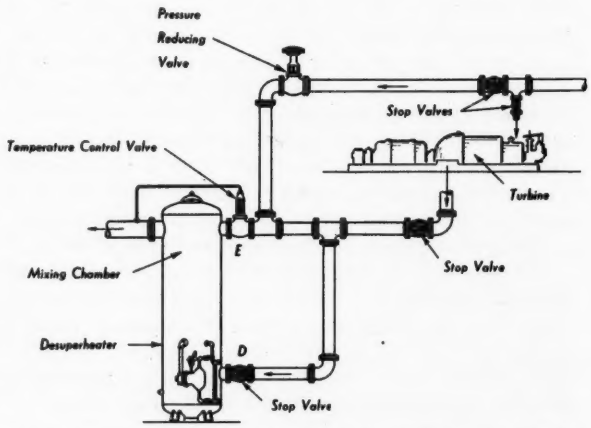


Fig. 4. Temperature regulation of turbine exhaust and bypass steam by so as to get the desired final temperature as used at Rochester. Details of the desuperheater are shown by Fig. 1J

to 865 deg. F. at no load. The temperature is held to 650 deg. F. by an evaporative surface or cartridge type desuperheater automatically controlled by the position of the turbine inlet governor valves and a thermostatic bulb in the turbine exhaust.

Although the illustration, Figs. 2, 3 and 4 show central station applications, it must not be inferred that the desuperheater has no place in industrial practice. As a matter of fact in the newer high pressure industrial plants the desuperheater is as indispensible as the pressure reducing valve. Not only must the old and new sections of the station be tied together through a pressure reducing and desuperheating station, but provision must be made to maintain process steam pressures regardless of momentary variation in the steam and electric load balance.

Control and regulator equipment, which plays such an important part in successful desuperheating practice is, in general, similar to that used for combustion control purposes. Master loading is sometimes used with a parallel control of spray water and reducing valve position so that the final temperature adjustment by the thermostatic element is small with the time lag reduced to a minimum.

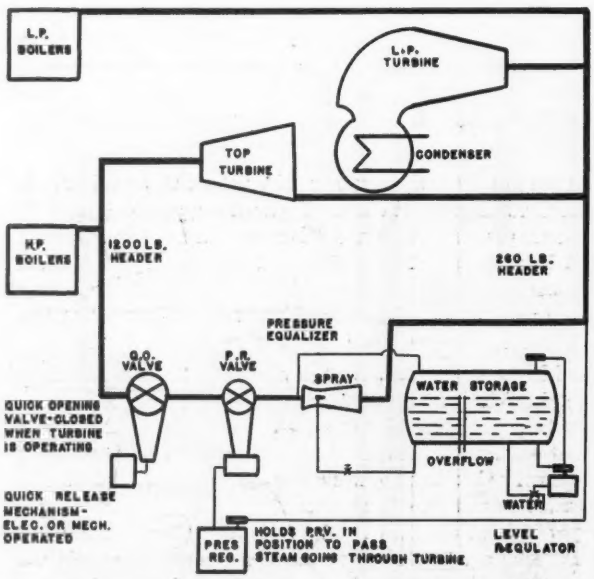


Fig. 3. Diagrammatic arrangement of a high capacity, high speed bypass and desuperheater unit in a recent station, West End. The arrangement at Fisk Station is similar. Temperature regulation automatically maintained by spray induced by steam flow through the Venturi throat as shown in detail by Fig. 1C

On the Way Out

Furnace gases pay in heat units at every turn from the time they leave the furnace until they are set free at the top of the chimney. Slag screens take first toll, baffles act as traffic cops, soot blowers dust off the customer and precipitators make him presentable for public appearance.

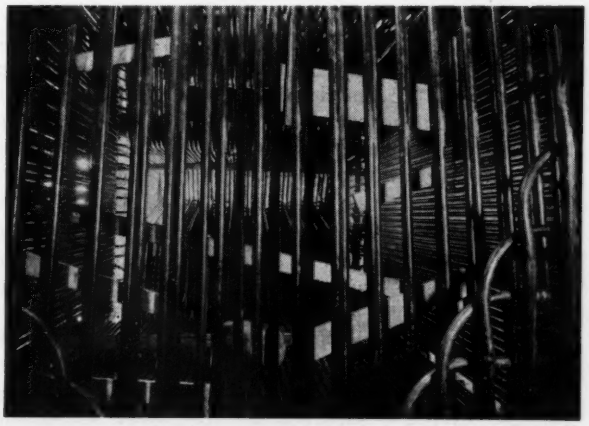
SUCCESSFUL operation of boilers depends in no small measure upon the design of the gas passages extending from the outlet of the furnace to the top of the chimney. In this space are located the water-heating surface, including boiler tubes and economizers, the steam heating surface, which includes superheaters and gas reheaters. All of this equipment is surrounded by gases which are discharged from the furnace at high temperature and lose their heat to the water and steam contained within the boiler unit as the gases pass to the outlet at the top of the chimney.

To direct the gases over the various heating surfaces in such a way that they will be most effective in transmitting heat, many arrangements have been devised for proportioning the flow and guiding the gases to and fro through the entire setting. For this guiding of the gases the usual method is to employ baffles. It may be stated here that tubular boilers require no baffles, as the flow of gases is through the tubes themselves.

Baffles are often of specially shaped tile or may be built of plastic refractory. In present practice cross baffling is used wherever possible since this method of baffling causes more rapid heat transfer than does the parallel baffling which formerly was used quite extensively. Various arrangements of baffling are shown in Fig. 2 and on other pages of this issue.

For horizontal water-tube boilers, the entrance to the first pass, as designed by many engineers, will cover about 42 per cent of the tube length, the second pass 33 per cent, and the third pass about 25 per cent. This proportioning is for the purpose of securing an even velocity through the heating portion of the boiler as the temperature drop of the gases through the setting reduce this volume. The velocity should be as high as is consistent with desirable draft loss since high gas velocity is productive of high heat transfer. In cases where parallel baffles are used on horizontal water-tube boilers, the entrance of the first pass covers, in average construction, about 30 per cent of the tube length, the lowest one or two rolls of tubes usually being exposed to the fire to absorb radiant heat. Entrance to the second pass covers 33 per cent of the tube length. For boilers of the bent-tube type, such as the Stirling, the entrances in common practice are, for the first pass, 28 per cent of the tube length; for the second, 20 per cent; for the third, 15 per cent. Cross baffles are placed so that gases are compelled to pass across the tubes, and with the design of gas passages such that velocity of gases will be the same as far as possible over all parts of the heating surface. For horizontal parallel baffles which lie along the tubes, either refractory block, C or T tiling may be used. The block and C tile surround the tube and are used where it is essential to form a roof over the furnace in order to hold the temperature above the kindling point. The T tiling, however, lies on top of the tubes, its only purpose being to prevent the gases from passing through.

In the design of baffling the engineer aims by directing the flow of the gases to aid the circulation of the boiler water in the tubes. Another object of the designer is to avoid dust pockets which reduce the active heating surface, and if this flue dust is in contact with boiler material it fosters corrosion, particularly if it becomes damp during shutdown periods and sulphurous coal is used. The designer must also endeavor to avoid gas



Photo, courtesy Combustion Engineering Co., Inc.

Fig. 1. Looking up through the slag screen protecting the hopper of a dry bottom, down-fired, pulverized fuel furnace under construction

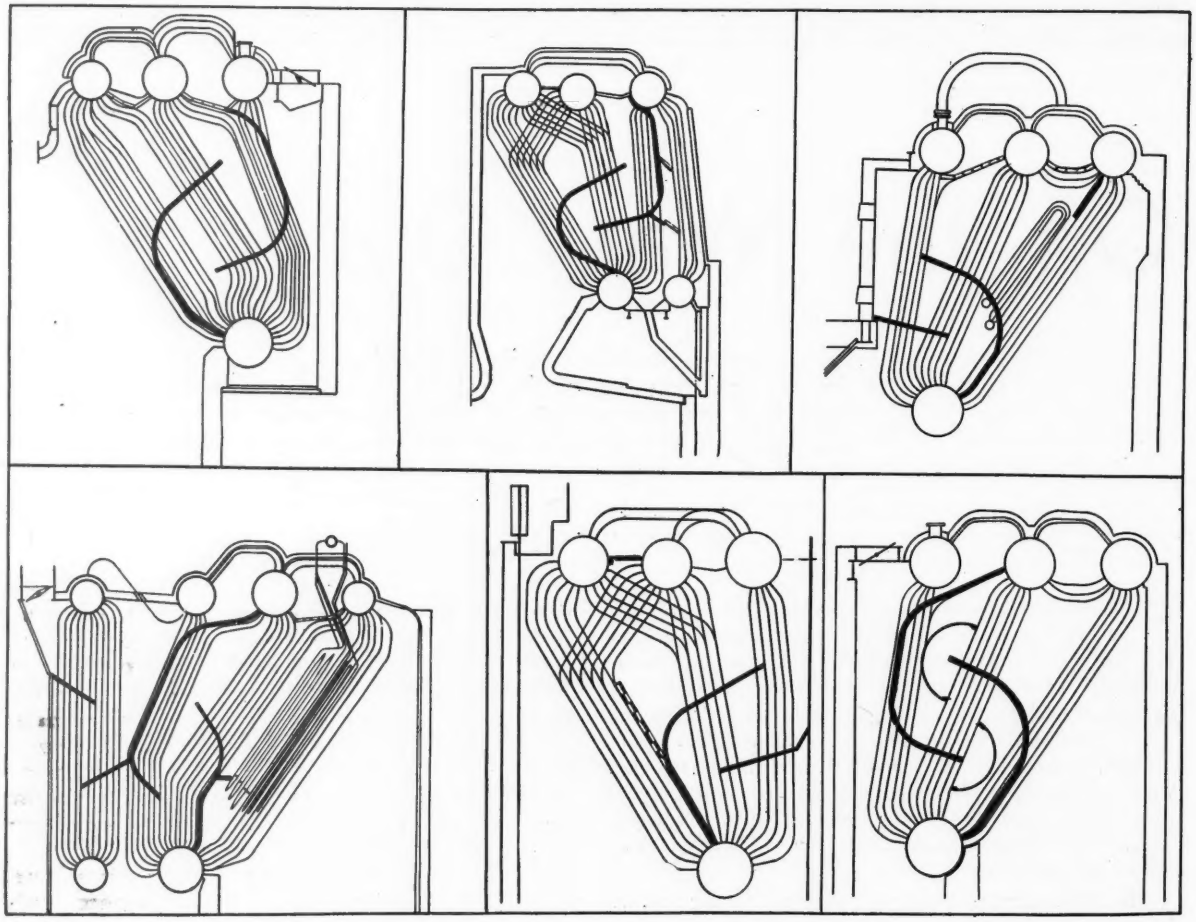


Fig. 2. Curved baffles that have been used successfully to meet different operating requirements

pockets. Baffles should be so located as to assist rather than interfere with soot blowing wherever this arrangement is possible. Removal and replacement of boiler tubes is at no time an easy job and where these tubes pass through baffles it becomes even more difficult. Baffles, therefore, should be so designed as to make this repair work as easy as possible.

Many modern boilers are designed with curved baffles, which make for flexibility of arrangement and reduce resistance to the gas flow. What is known as filter baffles are built of tile and are easily changed to suit operating conditions. Their function is to modify the flow of the gases by permitting some of them to pass or filter through but to divert the main flow in some other direction; these baffles are used conveniently around superheaters.

There seems to be no limit to the arrangement of baffling which is employed in the design of boilers, this arrangement being governed by the boiler design, steam conditions desired, and the fuel burned. Furnace temperature for a given heat release may be raised or lowered by changing the baffle position so as to confine or release the heat. Some parallel baffling functions in this way. By means of baffling, also, more or less of the gases are directed over the superheater tubes, thus influencing steam temperature. In economizers and air preheaters, baffling directs the flow of the gases to obtain the most desirable heating distribution and transmission.

In low temperature locations baffles may be made of steel, but in high temperature locations, refractory material or refractory protected material may be used, the metal held in close contact with water tubes to prevent it from being destroyed. Cast-iron T plates are used by some designers, these being arranged to fit the tubes closely and held in place by attaching to crossbars top and bottom, then covering with plastic refractory cement. In extremely high temperature locations interlocking tile is sometimes used. Monolithic construction, cast or rammed in place, makes an extremely flexible material for the building of baffles; special forms built to the desired shape, either straight, angled or curved, are required where this material is used.

Slag Tubes

As far as is possible by design methods, furnaces are so shaped and provided with means for preventing fly ash from being carried out of the furnace space into the gas passages of the boiler. One device commonly employed is an arrangement of water tubes in the form of a screen through which the gases must pass as they leave the furnace. The tubes usually form the first and second rows of the boiler and are spaced double that used with the regular boiler tubes in order to prevent bridging of the slag between tubes, and the second row is placed staggered with the first, thus exposing both rows to

radiant heat from the furnace. These tubes cool the molten particles of fly ash, causing them to collect as slag on the tube surface until the coating becomes so thick as to prevent transfer of heat rapidly enough to cause congealing on the outer surface, when the accumulation drips off into the furnace, the drops being too heavy to be conveyed in the current of furnace gases. Similar tubes are used across the bottom of dry pulverized fuel furnaces to shield the floor of the furnace from the radiant heat above and permit removal of the ash from the hopper in dry form. In both cases the water heated goes to make steam without loss of heat.

Soot Blowing

One of the most effective insulating materials encountered in power plant work is soot and fly ash, which seem continuously to deposit upon the boiler tubes while in operation. Soot is usually the result of incomplete combustion in the furnace, the combustion being stopped by the cooling effect of the heating surface and in this condition the gases precipitate free carbon in the form of soot which clings to the heating surface on the gas side of the metal.

Dust or fly ash also gives considerable annoyance, particularly from pulverized coal or where coal is burned on stokers at high rates, the fuel bed being supplied with forced draft. The accumulation of this soot and dust on the tubes is therefore relieved somewhat by proper operation of the furnace so as to secure complete combustion and by keeping the rate of combustion down so that the flow of gases does not carry with it great quantities of fly ash. In regular boiler operation, however, it is necessary to dust the tubes as a matter of routine practice from two to four times a day. This is done by means of soot blowers, which consist of a tube element extending across the gas passage in which are placed steam or air nozzles so spaced as to direct the flow of steam from them over the spaces between the tubes in the top row. The tube element is rotated so as to sweep a section of the tubes and thus dust off the light particles before they adhere tightly to the heating surface.

This tube element is supplied with steam from a valve mechanism on the outside of the setting and the rotating device is designed so that it can be conveniently operated from the boiler room floor. Soot blowers are so located in the setting as to direct the dust away from the heating surfaces back into the furnace or into hoppers provided to receive it, and at the same time they must be in space shielded from extremely high temperature.

In addition to dusting the tubes with soot blowers it is customary to brush these surfaces or scrape them mechanically at times when the boiler is out of service, since in many instances the tubes gather an accumulation of slag which adheres tightly to the tubes.

Fly Ash Collectors

One of the most difficult problems with which engineers have to contend is the nuisance caused by fly ash and cinders discharging from chimneys where the furnace is worked at a high rating. Furnaces fired by pulverized fuel are notable offenders. Among the early installations using this method of burning it was found that large amounts of fly ash or cinder were carried by the furnace gases, some of which was deposited on the furnace walls, some coated the boiler tubes and even bridged between them, some collected in pockets in gas passages, and the remainder was discharged from the chimney in such quantities as to become a nuisance in certain localities. It is reported that in some instances as much as 90 per cent of the ash was carried away from the furnace by the gases, only about 10 per cent being deposited in the furnace bottom. But most of these difficulties have been overcome, mainly by using relatively large furnaces with special air cooled or water cooled walls, by installing slag screen or air cooled or water cooled furnace bottoms, or by using slag tapping furnaces and by adopting suitable arrangements of boiler and flue passages, and as a last resort, by passing the gases through dust eliminators before discharging them to the atmosphere.

Fly ash collectors may be classified under three headings: mechanical separators including screens, baffle traps, cyclone collectors and rotating centrifugal separators; electrical precipitators which remove the particles of fly ash by charging them with electricity and collecting them on plates of the opposite polarity, from which they are dusted periodically; the third method is by hydraulic washing. This consists in passing the gases through a spray of water. There is much yet to be done in improving methods of preventing fly ash from polluting the atmosphere since none of the methods now employed are considered satisfactory by the engineers in charge of plants.

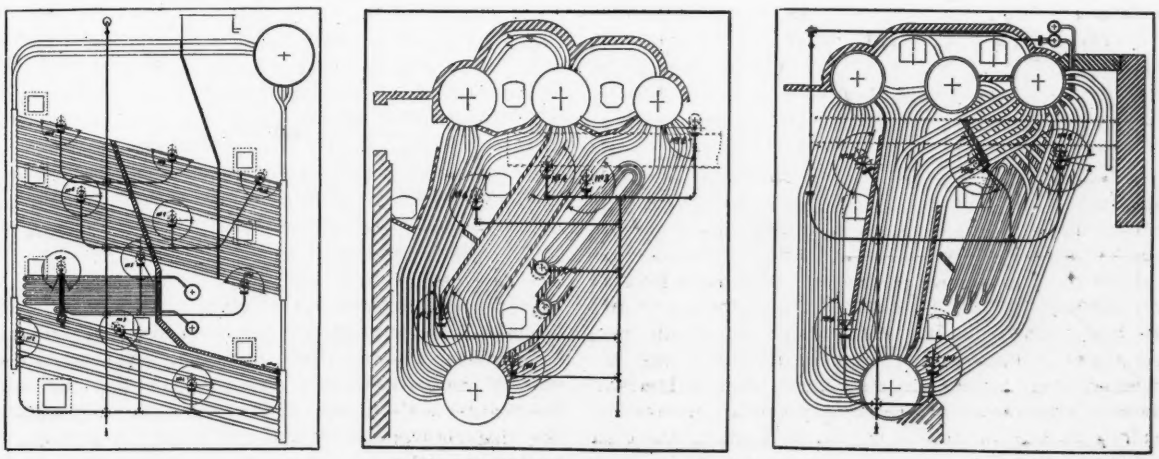


Fig. 3. Typical locations for soot blowing units

The expression "Washing steam" sounds silly, yet modern boilers make use of devices which do just that. What really happens, of course, is that moisture content of a high concentration is exchanged for one of a low concentration. After that the steam is passed through various arrangements of baffles called dryers to remove the moisture.

Steam Dryers and Washers

THE QUALITY OF WATER delivered to the boiler and the quality of the steam delivered by the boiler are both factors of great importance in modern boiler operation. Without modern systems of feed water treatment and preparation which produce practically pure water for boiler feed purposes it would be impossible to evaporate the hundreds of thousands of pounds of water per hour attained in modern practice for any length of time, without serious deposition of scale on all of the heating surfaces. Similarly, with regard to the steam delivered by the boiler, when it is realized that even a fraction of a part per million of contaminating solids in the steam may deposit many pounds of solids in the superheater as well as in the pipe lines and turbines, the importance of pure steam is equally obvious.

In modern boiler operation, therefore, it is imperative to keep the moisture content and the solid content of the steam down to the absolute practical minimum. In the early days a moisture content of 2 to 4 per cent was common, but today the amount of moisture that can be tolerated is less than one per cent and more often very much less. To show what moisture contents of 2 and 4 per cent mean in terms of water content the data shown in Fig. 1 is of interest. These curves, plotted by Sheppard Powell, give the amount of solid matter discharged per year for various ratings and also the amount of water carried over in the steam per hour. As will be noted, even with an output of only 40,000 lb. of steam per hr. and with a moisture content of only 2 per cent, over 3 tons of solid matter will be carried over with a boiler water concentration of 100 grains of solid matter per gallon.

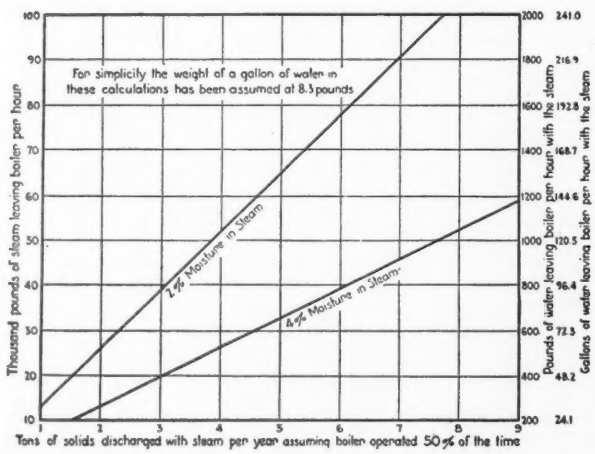

For simplicity the weight of a gallon of water in these calculations has been assumed at 8.3 pounds
2% Moisture in Steam
4% Moisture in Steam
Thousand pounds of steam leaving boiler per hour
Pounds of water leaving boiler per hour with the steam
Gallons of water leaving boiler per hour with the steam
Tons of solids discharged with steam per year assuming boiler operated 50% of the time

Fig. 1. Approximate weight of solids discharged from a boiler with wet steam when the boiler water contains 100 grains of solids per gallon

While more or less elaborate systems for treating feed water have been in use for many years, it is only within recent years that considerable attention has been given to the question of purifying the steam. True, steam purifiers to remove oil from steam after it has passed through the engines have been in use for many years with excellent effectiveness, but by steam purification here we have in mind its purification before, or at least immediately after, it leaves the steam drum of the boiler.

One of the earliest devices used to secure delivery of "dry" steam was to the simple dry pipe still used in many boilers. This consists merely of a pipe of about the same diameter as the boiler nozzle placed close to the top of the steam drum and perforated on its top side with many small holes. Steam rising from the water has to make a 180 deg. turn to enter the holes and as a consequence of this sharp turn drops much of its entrained moisture and with it other solid matter that may be present. With comparatively low ratings this scheme is quite effective and keeps much of the entrained water in the steam from entering the header.

With higher ratings, however, more elaborate arrangements have come into use, most of which fall into two general classes. One class effects the removal of moisture and solids by sudden changes in the direction of steam flow as in the case of the dry pipe. This method effects the removal by centrifugal force and gravity.

In the other class, the steam is actually "washed" by

intimate contact with the incoming feed water. Many of the latter type also use the first method to clear the steam of the entrained moisture it may have picked up in the washing processes.

The various arrangements available, although alike in principle, vary considerably in construction. In most present day boilers, these separators or washers are built integral with the boiler drum, but for boilers not so equipped, external units are available for installation in the main steam line from the boiler or on top of the boiler drum. In either case their operation is much the same. One of the first washing arrangements to be incorporated in the boiler drum was at South Amboy Station.

The various designs shown in the accompanying illustrations require little explanation since their operation is almost self evident. The type shown in Fig. 2 is a well known type usually installed in the steam drum, but it can be supplied for installation outside the drum where necessary. Steam enters the unit at the sides, passing through rows of vertical U-shaped baffles arranged in staggered formation so that the steam is split into a large number of thin streams, thus exposing a large surface to the scrubbing action of the baffles. Since these paths through the baffles are curved, a centrifugal separation of the particles is effected. As the steam emerges from each row of baffles, expansion occurs with a consequent reduction in velocity and this brings about further removal of suspended matter. The steam next passes into the central compartment through the longitudinal opening in the top and out through the steam nozzle. The moisture and the particles of solid matter removed by the baffles drains into a collecting trough at the bottom of the separator and is delivered to the feed water supply or to waste through a suitable trap.

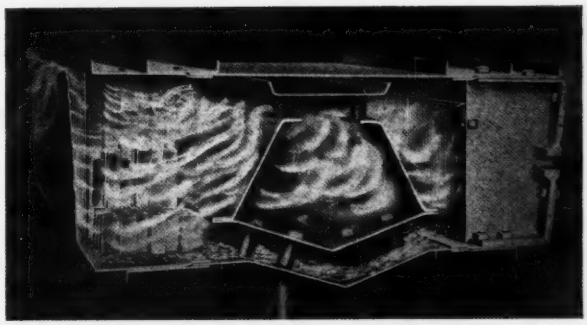


Fig. 2. A steam purifier using baffles centrifugal separation and change in velocity

Other types of centrifugal separators are shown in Fig. 3. As will be noted, some of these use vanes to impart a rotary motion to the steam and thus direct it to the walls of the chamber through which it flows. In others the steam has to flow through tortuous paths through banks or cartons of vanes and baffles. Various claims are made for each type, though fundamentally the principles involved are the same.

Various examples of the "washer" type purifiers are shown in Fig. 4. These differ in principle as to whether they are of the bubble type or the spray type, but all of them are based on the idea of bringing the outgoing steam into intimate contact with the incoming feed water. One form known as the contact tube type differs somewhat in construction from the ordinary bubble or spray types, but in principle it is a combination of both.

In some of these washers the steam bubbles through a shallow layer of feed water, while in others it is forced through a spray of feed water. The purpose in both

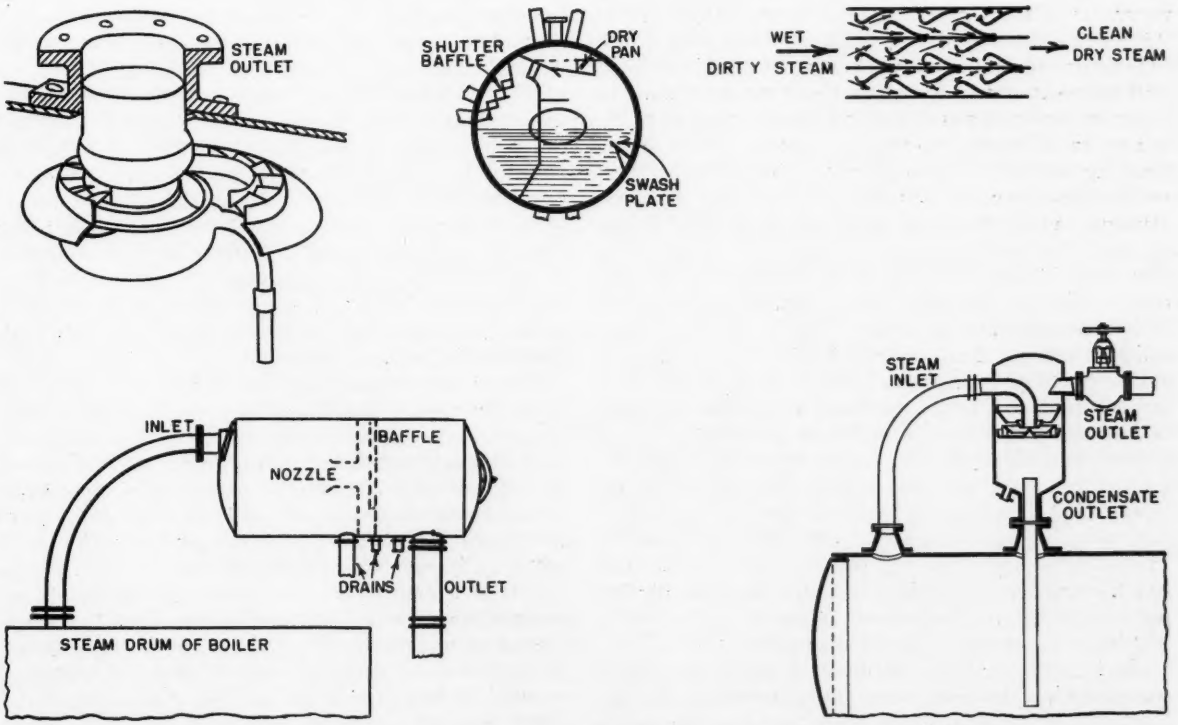


Fig. 3. Various types of steam dryers

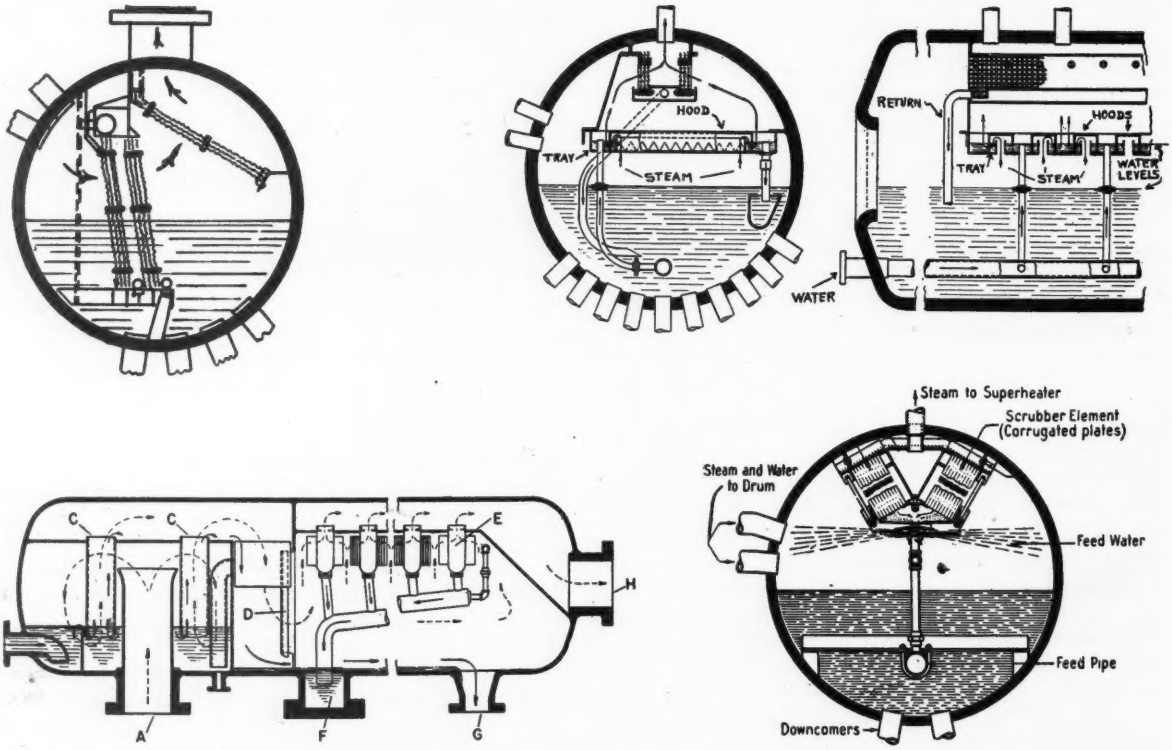


Fig. 4. Typical designs of steam washers

instances is to exchange the highly concentrated boiler water in the steam for the comparatively dilute feed water. It is evident that the moisture content of the steam after washing will be relativelly high, but it will be moisture of a dilute nature compared to that which it held before washing. Even this dilute moisture must be removed, however, and it is for this reason that all of the wet types of separators also incorporate dry type sections for drying the steam after it has been washed.

The type to use in specific installations is of course dependent upon the steam conditions demanded. Where the water is very pure, the dry type of separator may give entirely adequate results. A number of the dry type separators are sold with a guarantee based on "Standard Specification Steam," that is, steam having a moisture content of not over 0.2 per cent and total solids not in excess of 9 parts per million. In many instances this is entirely adequate, but where additional protection is desired the wet type separator is available. In some installations where the wet type washers have been installed, tests have indicated a total solid content in the steam of less than 1 part per million, when the boiler water concentrations run as high as 3000 parts per million. This was the case at the new plant of the Rochester Gas and Electric Co. where the feed water is practically 100 per cent make up. Tests there indicated total solids in the steam of from 0.3 to 2 parts per million.

It is obvious that regardless of these washers or separators it is desirable to maintain a relatively low concentration in the boiler water itself. In the early days this control of boiler water concentration was effected by "blowing down" periodically. This is effective, but in large installations is wasteful of heat and does not tend to maintain a uniform condition. In modern boilers this concentration control is effected through the use of continuous blow down systems. This, as the name indicates, consists in discharging a small amount of water continuously and reclaiming the heat so removed in the feed water by means of some form of heat exchange apparatus. In some systems the solids are actually removed from the blow-down water and the water itself returned to the boiler, but in others the blow-down water is discharged to the sewer and only the heat in it reclaimed. In any case, the purpose is to keep the water in the boiler at a relatively low and constant degree of concentration and at the same time to recover any heat that would otherwise be lost in the process.

There are several ways in which the heat of the blow-down water may be utilized to advantage. When the external feedwater treatment is by evaporators or base exchange substances, the make up may be warmed by the heat released from the blow-down water. Where hot chemical softeners are used the blow-down water passing through a heat exchanger may serve to heat the water on its way to the softener. In any case, the provision of a continuous blow-down system should not replace the regular blow-down valves since, even with such systems routine blowing down is desirable and often necessary. In plants where there is a deficiency of exhaust steam continuous blow-down systems are often particularly useful since they provide a means of heating the feedwater.

As designed and installed, boilers have definite limitations of operation, but the safe and efficient production of steam in accordance with the demand and at the lowest cost lies with the operating personnel.

BOILER OPERATION

BOILER PLANTS are built for the obvious and definite purpose of making steam at the lowest cost consistent with safety and reliability. For this reason, the designer usually gives considerable attention to balancing investment charges against operating costs. This balancing is largely a matter of experience and judgment based on rather arbitrary consumptions as to future load conditions, fuel costs, operating standards and depreciation.

Pressures and temperatures, more or less related, are sometimes fixed by process requirements but more often by the overall performance of the plant of which the boilers are but one part. As a rule high pressure, high temperature and high efficiency cost more because they involve more equipment and more expensive materials. The relation is not direct because it is influenced by contemporary practice and trends, with no bearing on the problem in hand except the cost of currently standard equipment is cheaper than that built special.

Operating efficiency is relatively unimportant in low fuel districts and consequently investment in heat reclaiming equipment is not justified to the same extent as in high cost fuel districts. Load conditions are important also. Base load operation, at or near full capacity a large portion of the time, justifies higher initial investments than does a standby or peak load plant that is operated but a portion of the time.

Operating Requirements

The rate of progress of the industry must also be taken into the picture. There is a sufficient background of experience to show that 20 yr. is an ultra-short period for the useful life of a well operated and maintained boiler plant. Few boilers reach that point, however, for long before they are worn out they are removed or retired to standby service in favor of newer or more efficient units. Proper rates of obsolescence and depreciation are impossible to determine, they are usually set arbitrarily, influenced greatly by accounting practice and tax procedure.

Estimating operating charges in advance is almost as much of a gamble, although somewhat more susceptible to control and readjustment in later years. After the boiler plant is built it must be operated to produce steam: First, safely; second, in accordance with the demand and according to specifications; third, as efficiently as the design permits; fourth, with the lowest operating, maintenance and repair costs consistant with the other factors.

This is not easy. It requires a well organized and capable operating staff trained to handle both routine operation and emergencies equally well, an adequate record and cost system handled preferably by the accounting department with the needs of the operating department in mind, the proper interpretation of these records and coordination with operating experience. The last two are beyond the scope of this article, the first will be covered in a general way.

Operating Code

No matter what equipment is installed or the extent of automatic control, the results over a period of time depend upon the plant personnel. To avoid confusion and insure complete coverage of all necessary details, the responsibilities of each man should be definitely fixed. This may be, in fact often is, done orally but the better method is by means of a written operating code. This is more necessary than ever because the modern boiler is much more complicated and sensitive than its predecessor and a man who has spent a lifetime operating may well be completely at sea in a new plant.

The extent of the change in operating technique is well illustrated by the fact that central station companies, manning new plants with experienced crews, find it advisable to conduct special classes to acquaint the men with the plant and their specific duties. The day has passed when a man could attend to his duties independently and without thought of his neighbor. Parts of the modern plant are so interrelated and interlocked that any change must be made with a full appreciation of its effect on other parts of the system.

Preparation of an operating code is not easy nor can it be outlined to any considerable extent because there is little or no standardization in plant practice. Some of the pertinent factors to consider are outlined in a special section of the A.S.M.E. Boiler Construction Code. These Suggested Rules for the Care of Power Boilers (published separately, price $0.70) cover routine operation, maintenance, inspection, prevention of direct causes of boiler failures and recommendations for feedwater analysis, treatment and control.

In the 1929 volume of the proceedings of the N.E.L.A., page 1131, is an operating code manual covering different types of plants. Portions of this appeared in Power Plant Engineering, pages 551, 626, 815, 932 and 1054 of the 1930 volume, and pages 292 and 653 of the 1932 volume. Details of the organization and operation of a large power plant appeared on pages 886, 1050 and 1163 of the 1929 volume of Power Plant Engineering and a complete operating code of the Hiram Walker & Sons plant in Peoria appeared on pages 158, 237, 362 and 432 of the 1936 volume.

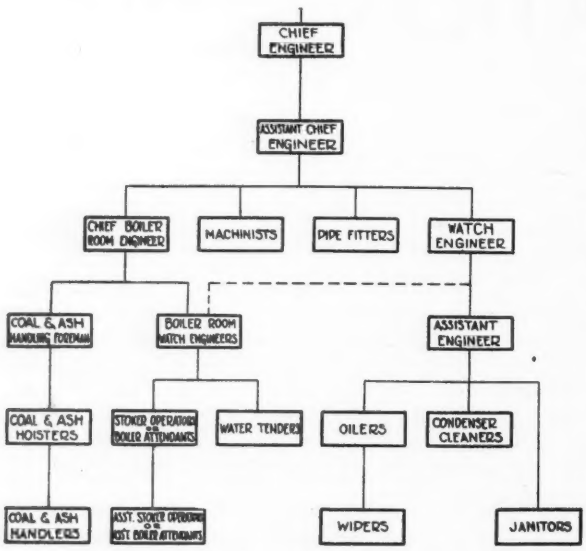


Fig. 1. Organization chart of the mechanical personnel of a large power plant which may be modified to meet conditions of smaller plants

With these references available for detailed study, there is little need here for more than a few of the more important considerations. Preparation of a specific code can best be made by combining the specific operating instructions of various manufacturers into a concise, coordinated manual.

Drying and Boiling Out

After the boiler is completed, the furnace must be dried out thoroughly and the boiler cleaned out. This is done by filling the boiler to about the middle of the glass and adding a solution of soda ash and caustic soda so as to give a final mixture equal to 1 lb. of each of the chemicals to each 1000 lb. of water in the boiler.

Drying the furnace is best done with a wood fire so as to give a slow heating of the refractories until all the moisture is driven off. The air supply should be generous so as to keep the furnace temperature to from 400 to 600 deg. F. until steaming has stopped. Flames should not be allowed to touch the walls as this may cause local expansion and spalling. The period of heating depends upon the type of furnace and refractories used, two or three days' drying is sufficient for most new furnaces with a correspondingly shorter period for repairs.

After the furnace is thoroughly dried out, the boiler should be closed and a slow fire, sufficient to maintain a steam pressure of about 5 lb. ga., held for two or three days. After boiling out this way the boiler should be emptied, washed thoroughly and filled with fresh water. This boiling out is to clear out all grease, oil and mill scale. If the boiler is kept clean the boiling out does not have to be repeated but if oil gets in accidentally, or intentionally for storage purposes, the boiling out process should be repeated.

Wet and Dry Storage

Practice in storing boilers for extended periods vary greatly. They should be thoroughly protected from corrosion internally and externally, the exact procedure depending upon the water available and the temperature and humidity of the atmosphere. The boiler should be cleaned and washed thoroughly inside and outside, using a hose if necessary on the fire side to remove soot and ash from the tubes and from all pockets where it may collect. It should then be dried thoroughly with coke jacks or a wood fire. Metallic surfaces can also be protected by a coating of oil applied with an atomizer. Settings should be kept closed but inspected frequently to guard against sweating or water leaks. On fire tube boilers the shell and tube surfaces should be given a coat of grease, red lead, black Japan or tar paint. The damper and all openings should be closed and quicklime placed in trays at several points in the settings to dry the air.

For short periods wet storage is more common. The boiler should be filled with water, deaerated if possible, and with an alkalinity in excess of 50 gr. per gal. This can be done by using 1.5 oz. of caustic soda per 100 lb. of water. The water should then be boiled for a considerable period with the vents open to allow the escape of all gases. Even under these conditions corrosion may appear as a result of incomplete deaeration, but it is felt by some companies that the addition of 2 or 3 lb. of sodium sulphite added to the boiler will stop this action and that boilers filled with deaerated water with a pH value of at least 11, sufficient sodium sulphate to establish the A.S.M.E. ratio and a small amount of sodium sulphite for complete deaeration, can be stored wet indefinitely. A piece of bright, clean steel should, however, be hung in the boiler where it can be inspected frequently and the unit must of course be protected against freezing.

For storage periods of more than 6 mo. it is usual to use the dry method. The boiler should be cleaned and dried as before and trays of quicklime, at least 20 lb. for each 1000 sq. ft. of heating surface, left in the drum. Additional protection is sometimes given by filling the boiler nearly full of water and adding about 1 in. of oil on top of the water. Draining the water out slowly over a period of 1 or 2 days leaves a thin coating of oil on the surfaces. The boiler should then be opened and air dried for two or three days, the lime added and the manholes and handholes sealed tight. The oil must be thoroughly boiled out before the boiler is put back into service.

Safety

From the operating standpoint, safety is always the paramount consideration as boiler and furnace explosions with a resulting loss of life and property are always a potential danger. Both the quantity and quality of feedwater are important and should be kept within definite limits. Low water endangers the boiler while high water promotes priming with resulting water hammer which endangers pipe lines and prime movers. Feedwater reg-

ulators as covered by a later article are used universally but this should not relieve the operator of responsibility for checking the water level by the gage glass constantly, keeping the glass clean, the columns blown down, and the try cocks working.

Poor feedwater endangers the boiler both by corrosion and scale formation. This too is covered in a later article. Scale decreases heat transmission and thus lowers operating efficiency. Its greatest danger, however, is in causing localized overheating of tubes or shell with subsequent weakening and bagging. A tube failure on a water tube boiler is not serious but the failure of a fire tube boiler shell is not only serious but usually fatal. When boilers are taken out of service they and the setting should be thoroughly cooled before draining so that soft deposits will not be baked on hard.

Blowdown

Boiler concentration is controlled by blowdown and here again caution must be exercised not only to see that the water is not blown too low but to avoid danger to other operators or repair men working on other boilers. Blowdown valves should be kept tight and because of their arduous service are installed in tandem. The valve next to the boiler should be opened wide before the second valve is touched. They should be closed in the reverse order. The first valve is thus kept in good repair and the second valve, which takes all the punishment, may be reseated if necessary without taking the boiler out of service. This does not remove the danger of scalding from blowdown from other boilers on the same line during the grinding, however. Boilers should be blown at periods of light load when the circulation is relatively slow and so that the large quantities of cold water do not cause disturbances. When a boiler, especially of the bent tube type, is being fired up, many companies make a practice of blowing down until the blow-off line is hot. This is done after pressure is raised, but before the boiler is cut in on the line, for circulation is sluggish until steam is being made and the blowdown assists in getting even temperature distribution.

Safety Valves

Safety valves too should be tripped periodically by hand to be sure they do not stick. Each time before the boiler is put into operation, but after pressure is raised to a relatively high value the safety valve should be worked by hand to free the valve and blow free any scale or dirt. Drains should be kept clear and the valve free of any confinement of pipe or support to avoid strains from expansion. Good operating procedure on low pressure boilers calls for periodic tripping of the valves, some plants going so far to demand it each shift. On very high pressures the valves will not stand frequent blowing and reliance must be placed on good maintenance at regular overhaul periods. It is not good practice to increase the boiler pressure until the valves pop. This results in excessive water loss due to the blowdown setting of the valve, and as the valves are ordinarily in multiple and set at different pressures, only some of them work. The superheater safety valve is ordinarily set lowest so that with dangerous pressures at no load the superheater is cooled by the escaping steam.

With oil, gas and pulverized coal, explosions must be guarded against and in any boiler the furnace should be under a draft with the outlet damper open and the induced draft, if one is used, operating to clear the furnace of gases and fumes before lighting up. If ignition is lost the furnace should be cleared before firing is resumed. Modern plants are provided with interlock systems so that the equipment must be started in the proper sequence, and so that the failure of any unit will automatically shut down all or a portion of the system.

Soot and Slag

Soot blowers involve an element of danger due to soot and dust which may collect on the tubes and in soot pockets. Soot blowers should be operated only when the boiler is in normal service with a sufficiently high rate of combustion to insure a low oxygen content in the flue gases, or, when the furnace is cold. During the soot-blowing operation, sufficient furnace draft should be available to prevent flare-backs or loss of ignition. The customary procedure is to increase the furnace draft well above the normal operating draft. When operating at the maximum capacity of the induced draft fan or the stock damper, this is accomplished by reducing the rate of combustion during the soot blowing period.

When burning high carbon, low volatile fuels, a large amount of carbon may be in the residue accumulating in the boiler setting. If this accumulation is on fire, operation of the soot blowers may result in an explosion. In this instance soot blowing should be done at times when there is a low oxygen content in the flue gases, and, the

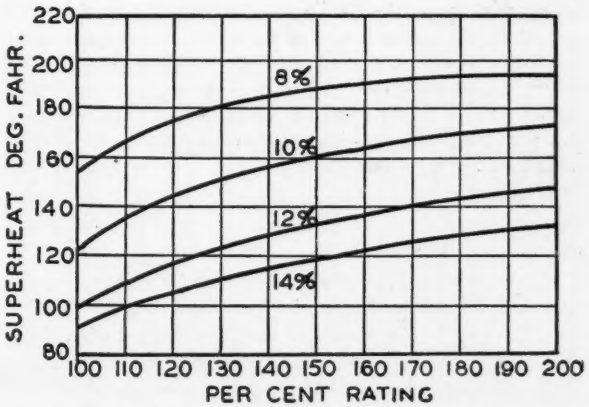


Fig. 2. High excess air has an appreciable influence on the superheat because the increased gas volumes result in better heat transfer

burner conditions are such that the soot blowing will not result in loss of ignition. If the soot blowing must be done when the boiler is out of service, first make certain there is no source of ignition in the furnace or setting which would result in an explosion. If the dust in the setting contains a higher combustible content, it is advisable to operate the soot blowers from rear to front and then from front to rear in order to minimize the amount of combustible dust blown into suspension.

When buring low carbon, high volatile fuels which have a low ash fusion point, considerable slag is generally deposited on the boiler. In this case, the best re-

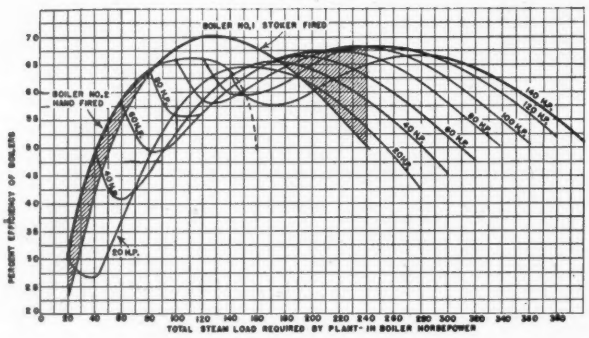

BOILER NO.1 STOKER FIRED
BOILER NO.2 HAND FIRED
PERCENT EFFICIENCY OF BOILERS
TOTAL STEAM LOAD REQUIRED BY PLANT- IN BOILER HORSEPOWER

Fig. 3. Careful division of load so as to get maximum efficiency pays dividends even in small plants. Changing the method of operation of these two boilers resulted in increase of 17 per cent in steam output with the same coal consumption. Figures on the curves represent the load of boiler No. 2. The highest possible combined efficiency for any load is given by the heavy curve at the top. Thus for a total load of 270 b.hp., the highest efficiency is 65 per cent, obtained when boiler No. 2 is carrying 120 hp. and boiler No. 1, the balance, or 130 hp.

sults, for removing this slag with the least expenditure of energy, can be obtained when the boiler load has been brought down to either a light operating load or a bank. Under this condition, the decrease in the furnace temperature will allow the slag to chill and be more readily removed by the soot blower.

Deslaggers

Soot blowers are universally used in modern boilers and the use of newer metals and alloys has reduced to a considerable extent warping of the elements and burning of the supports in the hotter sections of the boilers. Slag deposits on the first row of tubes can be removed effectively by water lances or by water cooled deslaggers recently developed for this purpose. Being water cooled with the spray water passing through an inner tube they may be hung below the tube bank without injury from the heat. Later units are built telescopic so that they may be withdrawn from the furnace when not in use. Deslaggers are operated in the same manner as a soot blower by rotating the spray element with a chain wheel or sprocket.

To a large extent the capacity and efficiency of the boiler depends upon the design. Coal selection offers some leeway to the operator but at a higher cost. It is well, therefore, to make a complete test or series of tests under favorable conditions when the unit is new. These should be more extensive than the acceptance tests and should give the operator complete knowledge of the limitations of the unit.

Efficiency

The boiler test procedure is outlined in detail by the A.S.M.E. Power Test Code on Stationary Steam Generating Units (Price $0.60) and need not be repeated. Some of the losses are controllable while some are not. The heat loss in the exit gases is the most important. This increases rapidly with the excess air and can be reduced to only a certain extent without danger of excessive loss in unburned combustibles. With stokers this loss is from combustibles in the ash pit and CO in the exit gases. With pulverized coal it appears not as CO but as unburned carbon. In addition to heat losses unburned combustibles igniting in the back part of the boiler results in secondary combustion which may cause disturbances in the boiler circulation. Moisture and hydrogen in the fuel cause water vapor with a corresponding loss of the latent heat.

Heat in the exit gases can be only partially reclaimed because of the danger of moisture forming in the economizer or air heater. Due to sulphur and CO_2 this moisture is highly corrosive and to avoid it the gases cannot be cooled below 300 or 350 deg. F. At low loads, especially with air heaters, the dewpoint is sometimes exceeded and to prevent this provision is often made to recirculate some of the hot air through the air heater by means of a bypass. This results in a lower temperature differential between the two sides of the heater with a corresponding drop in heat transfer. Sometimes the same effect is obtained by insulating certain troublesome sections of the air heater or by bypassing a portion of the air for combustion.

Heat Balance Tests

Heretofore boiler efficiencies have been made by measuring the heat content of the steam and the fuel. The same results can be obtained by measuring the losses and a test procedure based on this heat balance method is now being considered by the A.S.M.E. Committee on Power Test Codes. Properly used this method should be comparable to the standard procedure and much easier to apply to ordinary operating procedure.

The boiler must of course be operated so as to supply the necessary quantity of steam and it is quite important to the efficiency of the plant that the supply be at the designed pressure and temperature with as small a variation as operation permits. Temperature especially is affected by operating conditions, especially in boilers where no temperature control is provided. Superheat is very sensitive to excess air changes as shown by Fig. 2. Low excess air, or high CO_2, increases the furnace temperature but it also reduces the weight and volume of the gas flowing over the superheater and reduces the heat transfer because of the lower velocities.

Maintenance

A certain amount of maintenance work is inevitable but this, especially furnace maintenance, can be lowered by careful operation. Excessive furnace temperatures, caused by excessive loads, improper firing or poorly selected coal, causes high maintenance especially in refractory furnaces. Poorly selected refractory material is another cause. Some fuels give a slag particularly destructive to certain refractories and as with feedwater treatment the safest course to pursue is to put the problem of refractory selection up to a reputable specialist in that line. Rapid fluctuations in furnace temperatures should be avoided, heat transfer through refractories is poor and rapid changes in the temperature gradient causes spalling, or breaking away of the exposed surface of the brick. Water walls are less susceptible to slag troubles, as the slag builds up with a vitrified surface, runs off or cracks off according to

furnace temperatures. Flame impingement on the walls should be avoided regardless of the type.

Internal corrosion, primarily a matter of feedwater treatment and control, is briefly discussed in a later article. External corrosion is equally serious. Excessive corrosion of this kind is sometimes caused by cheap high sulphur coals. This is difficult to control and it is then a question of balancing the increased cost of maintenance against the increased cost of a better coal.

External corrosion can usually be traced to moist metal surfaces in contact with the atmosphere, soot ash or dirt. In bent tube boilers external corrosion usually occurs on tube surfaces near the drum or header and on tubes which support baffles where fly ash and dirt accumulate. Steam circulating tubes which support the roof of the setting also become coated with material which is corrosive when moisture is present.

In general, if a tube has corroded until its wall thickness, over an area with any dimension greater than the diameter, is less than 75 per cent of the original thickness, it is too thin to be depended upon and should be replaced.

Blank drum heads should never be concealed or embedded in the setting walls. Provision should also be made to keep these, and other surfaces clear of soot and leakage.

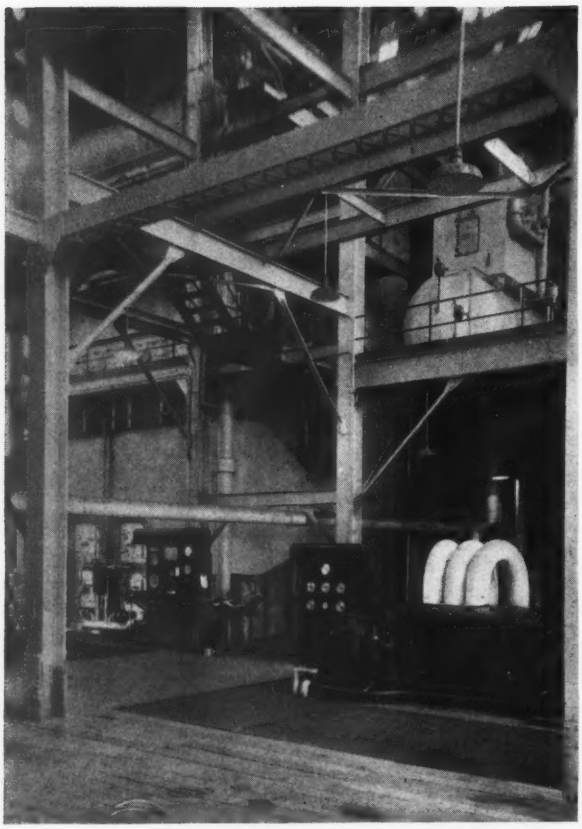
In h.r.t. boilers external corrosion is usually local in character due to leakage around manholes and handholes and the effects are much worse when this moisture reaches pockets where soot and ash have collected. Tubes of fire tube boilers are subject to corrosion also, usually because they become coated with soot and ash which absorbs moisture during periods of idleness. Rust is always a warning that corrosion is taking place and the source should be investigated.

Fuel represents about three-quarters of the operating costs of power production and so warrant the most attention. Maintenance is the largest variable, however, and requires close study and application. Operating personnel is a more or less fixed quantity which, however, varies considerably from organization to organization with individual opinions as to the requirements necessary for safe and reliable operation. It is also influenced by the design of the station and the attention that has been given to operating convenience. An accident from time to time seems to be the most effective reminder that the number of operators cannot be safely reduced without danger. Automatic devices and controls have two very definite limitations: first, they cannot think, anticipate emergencies or change their routine operation; second, they are effective only when in good repair. Probably one of the places where the biggest room for operating improvement exists today is in the care and operation of instruments and controls upon which the operators rely for guidance. The work should all be placed under one man, or group of men, with the ability and interest to give them proper care and attention and make simple operating adjustments.

Finally, it must not be forgotten that although good routine operation saves the pennies, a single emergency improperly handled will wipe out in a few seconds years of careful saving. The crew must be drilled and instructed so as to handle every conceivable emergency automatically and without hesitation. A few years ago a generator in a central station failed resulting in instant dropping of the load and the breakage of every window in the building. There was no damage done except that caused by the explosion, not a single boiler tube was lost, a remarkable example of what can be expected of a well trained crew in a well operated plant, a rare compliment to a capable chief engineer.

Boiler and furnace explosions are not as common as they were a few years ago due to better construction and operation. They do happen even yet, however, and several men lost their lives last year in this boiler room

Tribune Photo



The physical size of modern large boilers and the variety of auxiliaries has favored extended use of control equipment

BOILER CONTROL

Safe and efficient operation requires: steam pressure and temperature control with the fuel and air proportional to the load and to each other; removal of the gases of combustion; regulation of feedwater flow; and, in many cases, control of air temperatures for protection of air heaters and to give adequate drying of coal in the mills.

Complicated control equipment, so necessary for large modern boilers, has been subjected to intense development of recent years but the simple controls which have been well standardized for years offer a real opportunity for improved efficiency and operation in the small boiler field.

ALL FACTORS that contribute to the success and practicability of modern boilers are difficult, if not impossible, to classify. One of these is control equipment. As pressures, temperatures and rates of steaming increase, boiler operation becomes more critical because construction factors limit the water storage in the drum. In older lower pressure boilers this water storage acted as a cushion or accumulator to even out momentary fluctuations between steam load and heat release.

Boiler sensitivity has been defined quantitatively by Munzinger as the time in seconds for the pressure to increase 5 per cent after the steam load is cut off suddenly without any change in the fuel or feedwater supply. This depends on many factors, including the steam and water volume, the heat equivalent or storage and the rate of firing at the time the load is removed.

The once through boiler with a low water content is of course the most sensitive, the forced circulation next and the natural circulation least sensitive of all as shown by Fig. 1. The top curve is for a land boiler with 3 in. I.D. tubes and the second curve for a marine boiler with 1⅜ in. I.D. tubes, giving lower water capacities for the same heating surface. At a rating of 18.5 lb. of steam per sq. ft. (somewhat over 500 per cent) any regulation to prevent popping of the safety valves would have to take place in the following intervals: once through, 3.5 sec.; forced circulation, 7.5 sec.; small tube, natural circulation, 10.5 sec.; large tube, natural circulation, 22 sec.

Although natural circulation boilers still have an appreciable water storage volume in the drums, the tendency of recent years has been downward with the ultimate limit reached in the drumless once-through boiler. Before this point is reached, control equipment changes from an operating convenience to a necessity.

In the average modern boiler automatic control occupies a position midway between the two. The fact that these large units and their necessary auxiliaries can be controlled by comparatively simple means does, to a certain extent, make them practical or possible. Furthermore, the flexibility of the available control makes possible a degree of freedom in boiler and auxiliary design and layout that is a decided advantage in the large units.

For obvious reasons there has been a decided tendency to centralize these various controls so that the entire unit may be operated from a central point. Fundamentally it makes no difference whether the control be of the automatic or manual type, practically, however, the extra cost of adding automatic features to the remote or manual equipment is so slight that automatic control for the newer units is almost universal practice.

In addition to combustion, and feedwater regulation, the newer high temperature units demand control of steam temperature and in many cases air temperatures as well so as to give proper temperatures in the pulverizers and in the air heaters. Of necessity these complete controls are complex, for although the several functions are normally independent of each other they must allow coordinated operation by or with the boiler operator.

Automatic control must not, however, be considered as being confined solely to these large modern units. Ex-

cept under unusual load conditions, all boilers, even the simplest, are susceptible to automatic control in some degree even if this be limited to a simple furnace pressure or steam pressure regulator. On larger units control is an essential and integral part of the steam generator, on smaller boilers it is equally necessary for continued efficient and satisfactory operation.

Small Boilers

A simple and inexpensive control on a single boiler in a laundry plant will leave the operator free for other duties, and this alone may well pay a larger return on the investment than more complicated and expensive equipment that makes a decided fuel saving on a larger boiler. The startling improvements in complete and complicated control systems must not blind one to the fact that the simple, rugged and proven equipment that served earlier boilers is still available and because of the increased importance of efficiency, more important than ever to the smaller boilers that still form the major portion of boiler sales.

Safe and efficient boiler operation depends upon an adequate supply of water, fuel and air, furnished within certain limits in a definite proportion to the steam load and to each other. The first of these, water, is essential to the safe operation of the boiler and automatic feedwater regulators have been standard equipment for many years. Water is normally handled separately by feedwater regulators which are discussed in a later article. These regulators operate primarily from the water level in the drum, but of recent years the pressure in the feedlines in excess of boiler pressure, steam flow and momentary feedwater flow have all become factors of importance involved in the water supply problem.

Control of combustion equipment, usually covered by the general term automatic control, is fundamentally simple but in practice becomes more and more intricate as its range is extended to include more variables and the needs of complicated new boilers, especially if called upon to handle two or more fuels.

If we make certain assumptions and consider the valves and piping between the boiler drum and the steam header as an orifice, the pressure in the header is a measure of its steam flow or boiler load. This, the basis of the steam pressure regulator, is both practical and convenient and forms the starting point of combustion control systems operating today.

Steam Pressure Regulators

This steam pressure regulator is set to give, say, the necessary rate of firing for a definite steam pressure in the header. A decrease in load will cause an increase in steam pressure and the regulator will act to cut down the rate of firing accordingly. To meet a wide range of conditions and the needs of many plants these regulators are normally made with adjustments so that both the normal steam pressure and the pressure variation between maximum and minimum load is adjustable. Many different types are available using some variation of the Bourdon tube or diaphram. The tube or diaphram can be made very sensitive for it is arranged only to move a small pilot valve which controls the flow of water, air, steam or oil to a cylinder which incorporates the secondary or power cylinder. Sometimes only the contacts of an electric circuit are opened or closed and an electric motor does the actual work.

This gives a practical way of varying the rate of furnace heat release with the steam load but does not provide for supplying the fuel and air in the necessary proportions to give efficient combustion nor for removal of the gases of combustion from the furnace.

Practical methods of accomplishing these vary with: the fuel; the equipment to be controlled; established practice in operation; the control equipment selected; and, to a certain extent, the patent, situation. Edison said that a patent was nothing more or less than a license to go to law, yet it has been an important factor in the power field since the time when James Watt had to rack his brain to circumvent a patent on the crank.

With coal burned on grates, either hand or stoker fired, variations in the fuel flow are relatively slow but as the combustion rate is determined by the air flow, this offers practical method of quick regulation, leaving the coal feed to follow within its natural limitations. With pulverized coal, oil and gas the fuel and air may be varied together, although with units mills, allowance must be made for the time required for the coal to flow through the mill. Air or gas flow may be controlled by damper, by varying the speed of a fan, or, by a combination of the two.

Forced Draft

With natural draft the furnance pressure varies from a high draft at heavy loads to a low draft at light loads so as to draw more air into the fire as needed.

Forced draft is widely used with modern boilers, however, and it is common to maintain a constant or nearly constant furnace pressure at all loads not only because it gives better operation, but because high draft increases air infiltration while a positive furnace pressure gives high refractory maintenance. One regulator might conceivably handle fuel, air and flue gas but the practical difficulties of getting the necessary balance are such that it is customary to add a furnace pressure regulator which controls the furnace pressure by regulating either the forced draft or the draft at the boiler uptake. If several boilers are operated in parallel the steam pressure regulator on the common steam header may be used for all boilers but each boiler has its individual furnace pressure regulator.

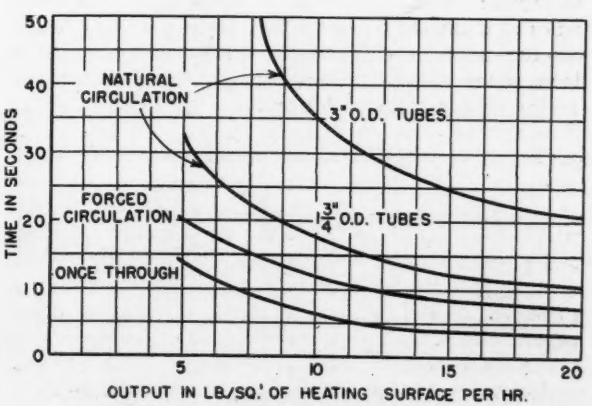


Fig. 1. The sensitivity of different type boilers as measured by the time required for a 5 per cent rise in pressure upon sudden cessation of load without change of feedwater or fuel supply

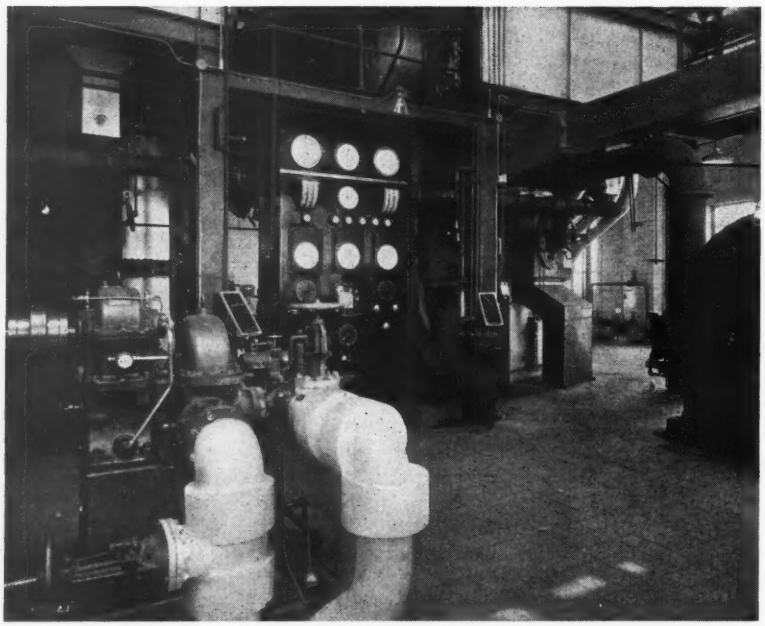


Fig. 2. Modern boiler control panels in an industrial plant with two pulverized coal fired boilers

Connections used between the regulators and dampers may be actual cables or shafting, electric circuits or lines carrying oil, air or water under pressure to secondary operating devices. The earlier controls used cable or shafting but, as the number and size of boilers and auxiliaries increased and the scope of the control broadened, electric and pneumatic transmission system were developed. In these a steam pressure regulator sends out, to one or perhaps several boilers, a secondary impulse bearing a definite relation to the steam load as determined by the header pressure. The master regulator may be the familiar spring or weight loaded diaphram or Bourdon element moving electric contacts, a small hydraulic jet or a leakoff valve. The impulse or master loading pressure may actuate two regulators on each boiler, or a single regulator on each boiler.

Which is used is determined by the fuel and the method of obtaining the ratio of fuel and air. Not only is it necessary to provide means of changing the ratio as desired, but it is necessary to provide means of compensating for the differences in the fundamental characteristics of dampers, fans and fuel feeding devices so that the fuel air ratio will be maintained over the operating load range of the boiler and to provide means for changing this ratio as desired.

Fuel-Air Ratio

The fuel characteristic is usually a direct function of stoker or feeder speed, while the air flow often approximates, over the operating range, the damper opening area, or, the square root function of a differential air pressure. As the fuel and air must be definitely linked together, some method of reconnecting or paralleling the two must be found. This is sometimes done by using special valves in the steam supply to steam driven auxiliaries or by cutting or setting cams either from theory or from actual boiler tests so that a movement of the regulator piston or change in loading pressure changes both fuel add air supplies proportionately. A compensator may be used to maintain a constant CO_2.

Another method is to actually measure the fuel and air supply as nearly as possible. Fuel is commonly measured by an electric or pneumatic tachometer on the feeder or stoker, although it is sometimes determined by measuring the primary air supply to the pulverizer. Air supply may be measured by means of an orifice in a duct, but more commonly by measuring the pressure drop across some section of the boiler. Another method is to proportion the air supply to the steam flow because for given conditions of operation the fuel feed bears a direct relation to steam flow.

In the usual steam pressure regulator, pilot valve and power piston are usually, but not always, built integral, with a master regulator the power device is separate and located at the machines to be controlled. This may be a damper, stoker or fan, engine or a speed changing device of some kind. Sometimes both speed change and damper control is used and this of course adds further complications.

Temperature control of steam, regulation of feedwater and water treatment are covered in later articles. Control of air temperatures necessary in some plants is usually accomplished manually by dampers equipped with direct or remote control.

Air Temperatures

Air heaters are often equipped with bypass and recirculating ducts, to prevent the gases of combustion being cooled below the dewpoint at very light loads and to prevent excessive air temperatures at high loads. In pulverized coal plants it is customary to dry the coal in the mill by means of hot air. Temperature requirements vary with the moisture content and the primary air supply is tempered or controlled by means of dampers so as to mix hot and cold air in the quantities necessary to give the desired temperatures.

Steam Temperature Regulation

Many methods developed but the present trend in design for high temperature stations is toward the use of bypass dampers to vary the rate of gas flow over the superheater surface

REGULATION of the final temperature of steam leaving the unit is but one of the several problems in boiler control, yet perhaps the most involved for it is influenced not only by boiler design but by boiler operation and superheating control devices as well. A superheater, or reheater, for the two are fundamentally the same, has a natural characteristic determined by the design, baffling and general arrangement of the boiler.

This natural characteristic varies with operating factors such as fuel, excess air and feedwater supply, and may be changed arbitrarily by several methods which will be discussed later. Temperature control as an operating problem is comparatively recent. It first came into prominence about the same time as, and partially as a direct result of, the reheat cycle, and partially as a result of the demand for improved heat economy which brought the reheat plant into being.

Superheaters and reheaters as an integral part of the boiler have been covered in detail in earlier articles and need not be considered here, except in relation to the turbine and general heat cycle of the plant. Inasmuch as the problem of temperature control first originated in the reheat plant and its development there has a direct bearing on the present problem of superheat control, it will be reviewed briefly to serve as a background.

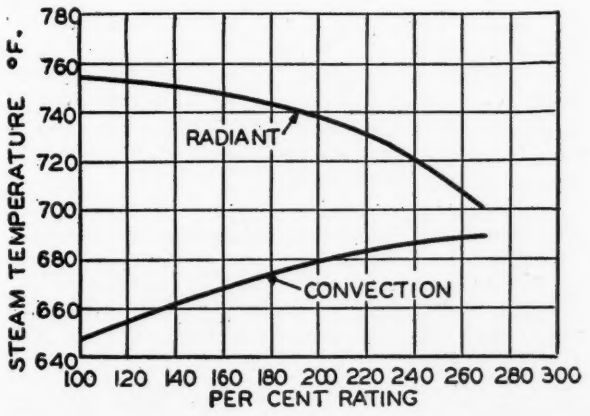


Fig. 1. Convection and radiant superheaters have different characteristics. Convection surface is commonly used for superheating but radiant surface is used to a limited extent in combination superheaters for control purposes

Natural Characteristics

With the convection superheater or reheater the steam temperature decreases with the load as shown by Fig. 1, partially as a result of decreasing gas velocities, partially as a result of lower gas temperatures due to cooling by the water wall and boiler surface. The radiant superheater or reheater has an opposite characteristic as shown by the curve in Fig. 1. This is due to the fact that the furnace temperature and consequently the heat transfer does not vary greatly with load and the heat available must be taken up by a decreased quantity of steam. The two types of surface may be combined in series to give a constant final temperature as discussed later. Application of the radiant superheater is, however, relatively new and its use quite limited.

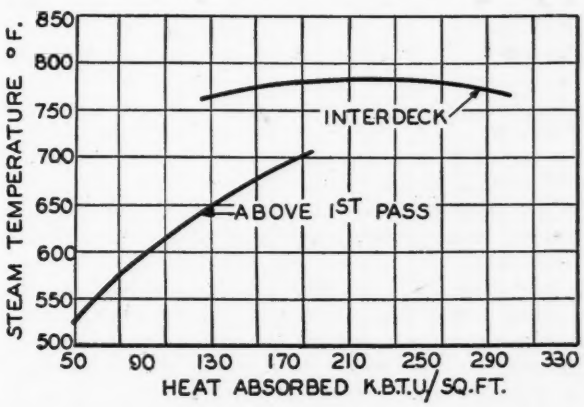


Fig. 2. As the convection superheater is moved closer to the furnace the characteristic changes due to the increased influence of the radiant heat transfer. These curves show the effect of tripling the superheater surface and moving it from the first pass to an interdeck position. Boiler capacity was increased by adding waterwalls and more economizer surface

In early boiler units superheat control was simple, the superheater surface was designed to give the desired temperature at full load and partial loads took care of

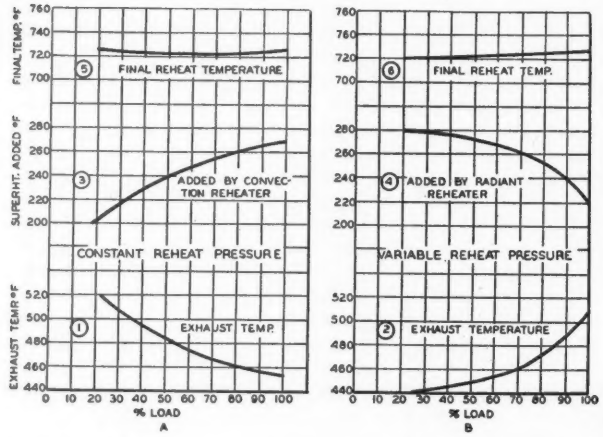


Fig. 3. The choice of a reheater is influenced by the method of operating the turbine. In top plants, as in the original Edgar and Lakeside units where the high pressure turbine operates at constant back pressure, the convection reheater works in nicely as shown by A. With cross compound units and a variable crossover or reheat pressure, the radiant reheater works best as shown by B. Port Washington uses a radiant reheater and the new Twin Branch station will use one, too

themselves. This had an adverse effect on efficiencies at lower load, but extremely high heat economy was not so important then. As higher temperatures developed and the need for partial load efficiencies increased, the problem more or less took care of itself because the superheater surface was moved closer to the furnace. This increased the radiant effect and the superheat curve flattened out, the change being shown well by Fig. 2. The boiler is fundamentally the same in both cases. Waterwalls and increased economizer surface increased the steaming capacity, but the increase in steam temperature and change in the shape of the curve came from tripling the superheater surface and moving it from the top of the first pass to an interdeck position.

Separate Boiler

When reheat first came into use, temperature regulation was made relatively simple by the use of a separate reheat boiler in which the rate of firing could be varied with the demand. This was not universal practice, for a movable baffle to control the gas flow over the reheater surface as well as combination radiant and convection surfaces were used early, but it was more common.

Early high pressure reheat plants were topping units and the high pressure turbine exhausted at constant pressure into the low pressure system. Operated in this way the turbine exhaust increases at light loads as shown by Fig. 3A. This works nicely with a convection superheater to give a nearly constant reheat temperature at all loads.

When the high pressure turbine is operated as part of a cross compound turbine the high pressure exhaust or crossover pressure is variable and the steam temperature drops at light loads as shown by Fig. 3B. In this case the radiant reheater fits in nicely to give constant reheat with totally different initial conditions.

Combination Superheaters

A combination superheat could be used in either case but so far these have been limited in application, the degree of control desired being obtained by other means. The importance of superheat control has increased for several reasons. First, better metals have made higher temperatures possible, while better knowledge of their properties has made it possible to operate closer to the allowable limit and safety demands that the operating temperatures be held to definite operating maximums. Second, the increased cost of these alloys places a premium on efficient operation. Most plants operate on full loads only a small portion of the time, and if the full possibilities of high temperature are to be realized, part load efficiencies must be kept as high as possible.

Desuperheaters

Superheat temperatures cannot be increased above that given by the natural characteristics but by increasing the surface the desired steam temperature can be obtained at the minimum operating load, and excess temperature at higher loads can be reduced by means of a desuperheater. Such an arrangement is shown by Fig. 4. Obviously this may be used for either reheat or superheat control and with any type of desuperheater. The one shown uses boiler water and the saturated steam

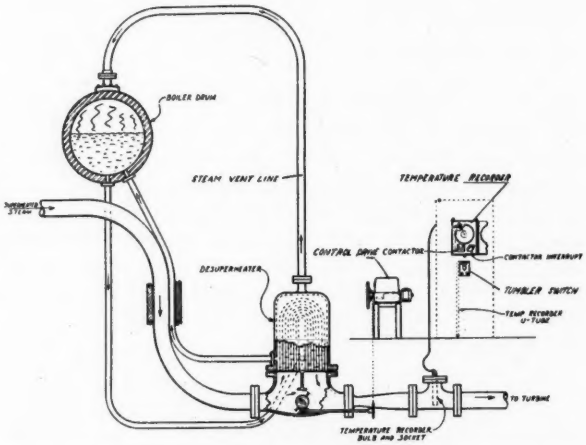


Fig. 4. Steam temperatures control by means of a desuperheater operated by thermostatic control from the outlet steam temperature. Any type desuperheater may be used, the one shown uses boiler water and the saturated steam generated is returned to the boiler drum

formed is returned to the boiler drum. Other types of desuperheaters are discussed in the article on desuperheaters. Sometimes the desuperheater is located in the steam drum itself. An arrangement of this kind, with the temperature control elements as shown by Fig. 5, is used in Lynn Station and the desuperheater tubes in the front drum are visible on the boiler section shown in a later article.

An arrangement of this kind has one disadvantage, it protects the turbine and piping from excessive temperatures at heavy loads but does not protect the superheater itself. Such protection can be obtained, however, by dividing the superheater into two sections and placing the desuperheater between them as shown by Fig. 6. The primary superheater takes saturated steam from the drum, superheats it partially and discharges to the secondary section for final superheating. A desuperheater placed between the two sections and controlled thermostatically from the final steam temperature works out nicely.

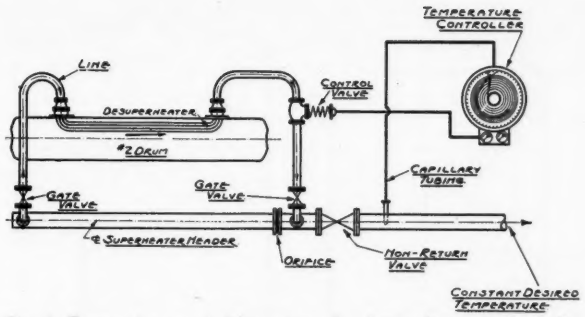


Fig. 5. Temperature control by means of a desuperheater in the boiler drum as used at Lynn Station. The temperature controller maintains a constant steam temperature to the turbine by bypassing a portion of the steam through the desuperheater tubes. An orifice in the superheated steam line creates a differential pressure which causes a flow through the desuperheater tubes when the control valve is opened. The actual arrangement of the tubes in the front drum can be seen in the boiler section shown in a later article

Temperature curves of a typical two stage superheater are shown by Fig. 7. This superheater is designed to give full temperature at about 55 per cent of full boiler output. The desuperheater acts to reduce the temperature entering the second section and thus limits the final superheat. The section shown crosshatched represents the effect of the desuperheater and the heat removed is of course utilized to generate saturated steam. At light loads the superheater thus acts indirectly as steam making surface and in this particular case supplied about 10 per cent of the total steam output at full load.

Because of the higher cost of alloy steel, superheaters for high temperatures are commonly made in two sections, but the addition of a desuperheater introduces complications and has not proved popular in this country. It is, however, widely used in Europe.

Bypass and Baffles

Present practice in superheat control in America shows a decided preference for bypass damper arrangements. Several typical designs are shown by Fig. 8. The first A, is a double boiler with three superheater sections, one bank on each side of the boiler lightly screened so that they closely approach the radiant type, and a convection bank on one side. Dampers control the gas flow over the convection bank and give the desired control over a wide load range as shown by Fig. 9.

The second arrangement, B, which is used with both straight or bent tube boilers bypasses the superheat with a portion of the hot gases, through an idle pass of the boiler, the resistance of the superheater tubes being sufficient to cause the gas to flow through the bypass area as the control damper is opened. Figure 10 shows the temperatures reached for various quantities of gas flow over the superheater. The superheater area is such that maximum steam temperatures are reached at 50 per cent load and 95 per cent gas flow.

In the third arrangement, C, the boiler is divided in two parallel gas passages by vertical baffles either parallel or at right angles with the drum. The superheater and part of the economizer are located on one side and the balance of the economizer on the other side. Gas flows over the two sections are controlled by dampers as shown.

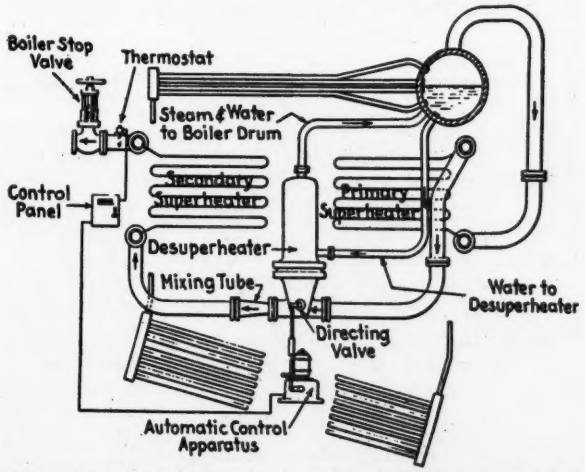


Fig. 6. By dividing the superheater surface into two sections with a desuperheater between them the last part of the superheater is protected from excessive temperatures. The control characteristics of a desuperheater of this type is shown by Fig. 7. The desuperheating action is thermostatically controlled so as to maintain a constant steam temperature at the superheater outlet

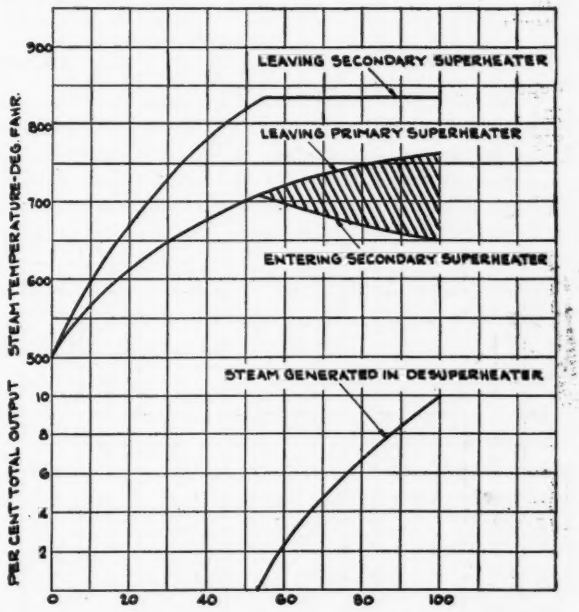


Fig. 7. Temperature characteristics of a two stage superheater with a desuperheater between as shown by Fig. 6. The crosshatched area shows the effect of the desuperheater. The saturated steam formed by this heat removal does, in this case, represent about 10 per cent of the total boiler output at full load

In the fourth arrangement, D, separate superheat control burners located directly opposite the superheater are used. These burners, high up on the furnace walls, are not materially affected by the water wall surface in the furnace and the gases enter the superheater at a high temperature. As the boiler load drops the heat input of the control burners is increased. By proper balance of the two sets of burners the steam temperature can be maintained constant regardless of boiler output.

Such a scheme will be used in one of the two boilers at the Windsor Station. The second boiler has a different arrangement. The furnace is divided, each section having a convection superheater section and in addition one side has a radiant superheater section. Steam temperature for the complete unit will be obtained by varying the heat input or rate of firing in the two sides of the furnace.

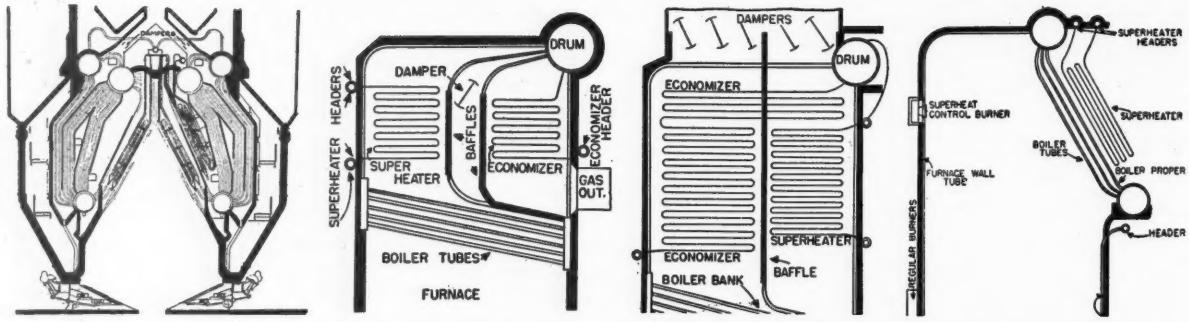


Fig. 8. Four methods of superheat control. A, with a double bent tube boiler, uses three banks of superheaters, two banks are close to the furnace and have a naturally flat temperature characteristic because of the radiant heat effect, the third bank is a typical convection superheater and final temperature regulation is by means of gas flow over this section under the control of dampers. B, may be used in either straight tube or bent tube boilers and consists of a gas bypass or short circuit passage around the superheater. C, used with single pass straight tube boilers, consists of dividing the furnace with a baffle parallel or at right angles to the boiler drum and locating the economizer and superheater surface so that the gas flow may be divided as desired by means of dampers. D, utilizes special superheater burners high up on the furnace wall where the water wall cooling effect is small. The heat release through these burners is increased at lower loads

Heat absorbed by the convection superheater surface depends primarily upon the extent and arrangement of the elements; the temperature of the gasses entering the superheater; and, the velocity and distribution of gasses through the tube bundle. Thus after the elements and the baffling have been installed changes in superheat is influenced primarily by operating conditions.

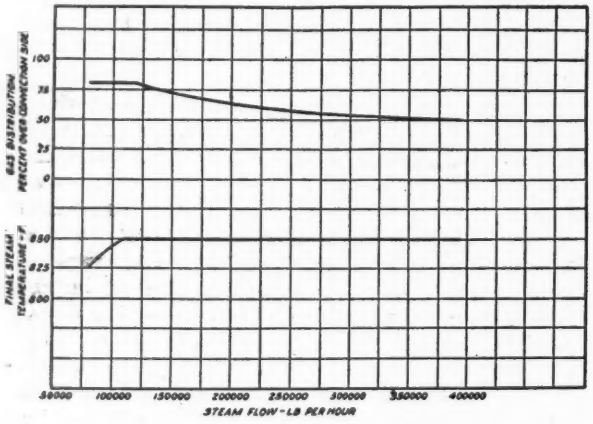


Fig. 9. Predicted performance of a compensating superheater of the type shown by Fig. 8A

Among the operating factors affecting the heat transfer are: cleanliness of the metal surface; variations in the fuel analysis; variation in excess air; variations in feedwater temperature and flow which is indirectly influenced by the boiler blowdown.

Deposits on the gas side of the superheater from slag or flyash, decreases the heat transfer. Deposits on the steam side from carryover, obviously have the same effect but are more serious because they lead to overheating of the tube metal and early failure. Local overheating may also be caused by poor steam distribution through the tubes and by poor distribution of gas across the furnace.

For this reason the superheater header arrangement is of the utmost importance where equal distribution cannot be obtained by any other means, orifices or plugs are sometimes used in the ends of the elements to equalize the steam flow. Recent high temperature boilers are built with a large number of saturated steam leads or connectors leaving the drum as it has been found extremely difficult to get equal distribution in the superheater inlet header of large units with but a single large connection.

Gas can be controlled by baffles which should be arranged to give a uniform flow and temperature over the length and width of the superheater. Baffling changes can be used very effectively to influence the natural characteristic of the unit.

Effect of variation or changes in fuel analysis is due primarily to accompanying changes in the volume of combustion gasses and therefore have the same effect as changes in the excess air or CO_2 content as mentioned earlier. The effect of feedwater temperature on superheat is not commonly appreciated. Increasing the feedwater temperature causes a decrease in superheat because for a given fuel consumption or gas flow, the steam generation is increased. The effect depends upon operating conditions but will range around 1 per cent change in superheat for a 10 deg. F. change in feedwater temperature. Sudden increases in feedwater flow will have an opposite effect because the rate of steam generation is momentarily decreased.

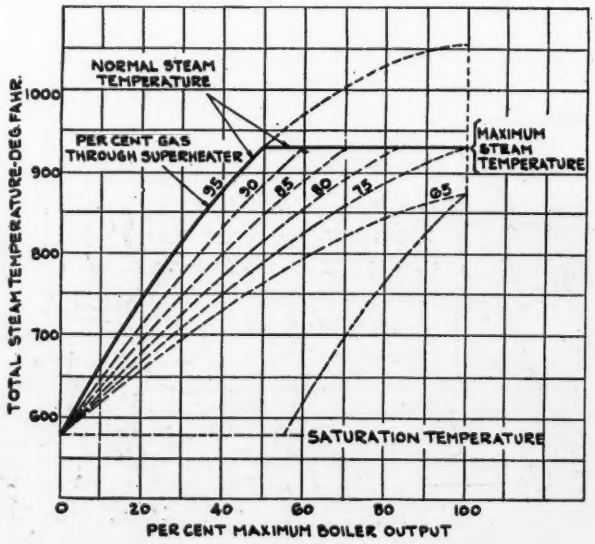


Fig. 10. Superheat control characteristics of a boiler with controlled gas flow arranged as shown by Fig. 8C, with two parallel passes between the boiler surface and air heater. The superheater and part of the economizer is in one pass and the balance of the economizer in the other. The gas flow through the two sections is positively controlled by dampers at the entrance to the air heater

Feedwater Regulation

UNDER the urgent demands for safety, feedwater regulators early earned a place as a necessary boiler appurtenance. Low water is a frequent cause of boiler explosions while high water promotes priming and endangers pipe lines and prime movers. Early boilers, in fact the low pressure boilers in use today, have generous water storage capacity and the problem is relatively easy to handle by the simple float or expansion elements shown by C, E, and F, operating the feedwater valve direct by means of linkage.

In another type the feedwater valve is operated by steam pressure, with the pressure usually varied in accordance with steam flow by a leak off port or pilot under control of the float or other actuating medium. Thus in A, steam is admitted to the top of the water control valve by a small combined steam valve and leak off port linked to the float. The effective steam pressure on the control valve varies from full boiler pressure to zero depending upon the position of the water level. In B the effective pressure is determined by the relative flow of water and steam through the central tube in the water column. On small boilers electric controls are sometimes opened and closed to control the operation of motor driven pumps.

If but one boiler is used any of these regulators can be made to move steam valves and thus control the speed of steam driven boiler feed pumps, instead of operating the feedwater valves. Usually several boilers are used, however, and it is customary to use some type of pump governor and a common form is shown by D. This is a spring loaded diaphram valve, normally open with the pump discharge pressure piped to the top of the diaphram and the bottom open to the atmosphere. Thus connected the governor will operate the pump to maintain a given pressure in the feed line.

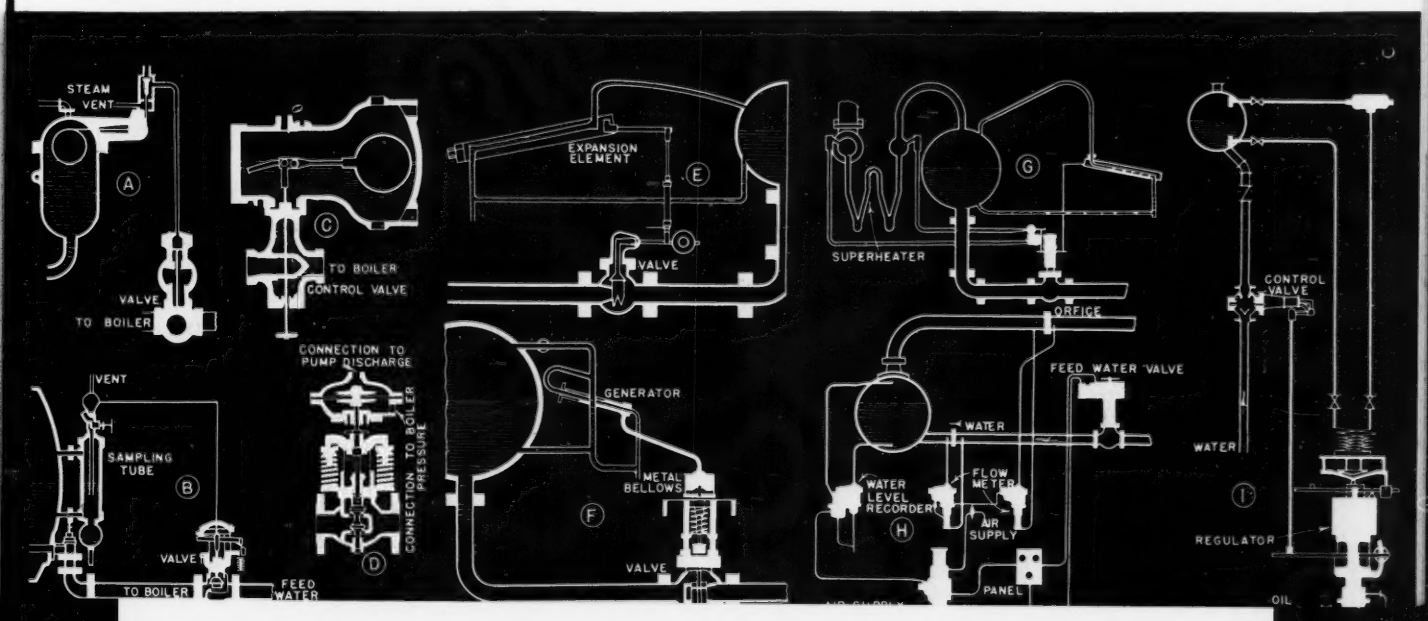
As pressures increased the water level control became more critical and to improve regulation the excess pressure regulator was added to maintain a constant differential pressure across the feedwater at all times so that the flow into the boiler would always bear the same relation to the valve lift. With one boiler in the plant the pump governor can be used for this purpose by piping the boiler pressure under the diaphram of the valve at D.

When more than one boiler is used a separate excess pressure regulator must be used for each boiler. In this case the boiler pressure is piped to the bottom and the pressure in the line between the excess pressure valve and the feedwater valve to the top. This results in a constant pressure differential across the feedwater valve.

When 600 to 800 lb. pressure first came into use "swell" occasioned considerable trouble. This is caused by the difference between the volume of steam and the water from which it is made. Upon a sudden increase in load, the increased volume of steam in the circulating water increases the total volume and causes a sudden rise in water level. A simple float regulator would thus cause a drop in feedwater flow at periods of sudden heavy loads. At higher pressures the effect is not so apparent and would disappear entirely at the critical pressure when the specific volume of steam and water are equal.

In any event, feedwater regulators responsive to both boiler water level and steam flow, as in G, and, to boiler water level, feedwater flow and steam flow, as in H, were developed. A later design, I, is actuated by boiler water level but the differential pressure across the valve may be varied in accordance with the steam flow so that it may be made responsive to two variables.

By varying the influence of the different variables and by proper design of the valve ports practically any desired characteristic can be obtained. In the smaller and low pressure boilers the majority of regulators move the feed valve direct or through linkage, but, many of the larger high pressure installations use pilot valves with the power cylinders operating the feedwater control valves moved by external means. Thus the regulator H uses air pressure, and I oil pressure, and G, air, oil or water whichever may be the most convenient.



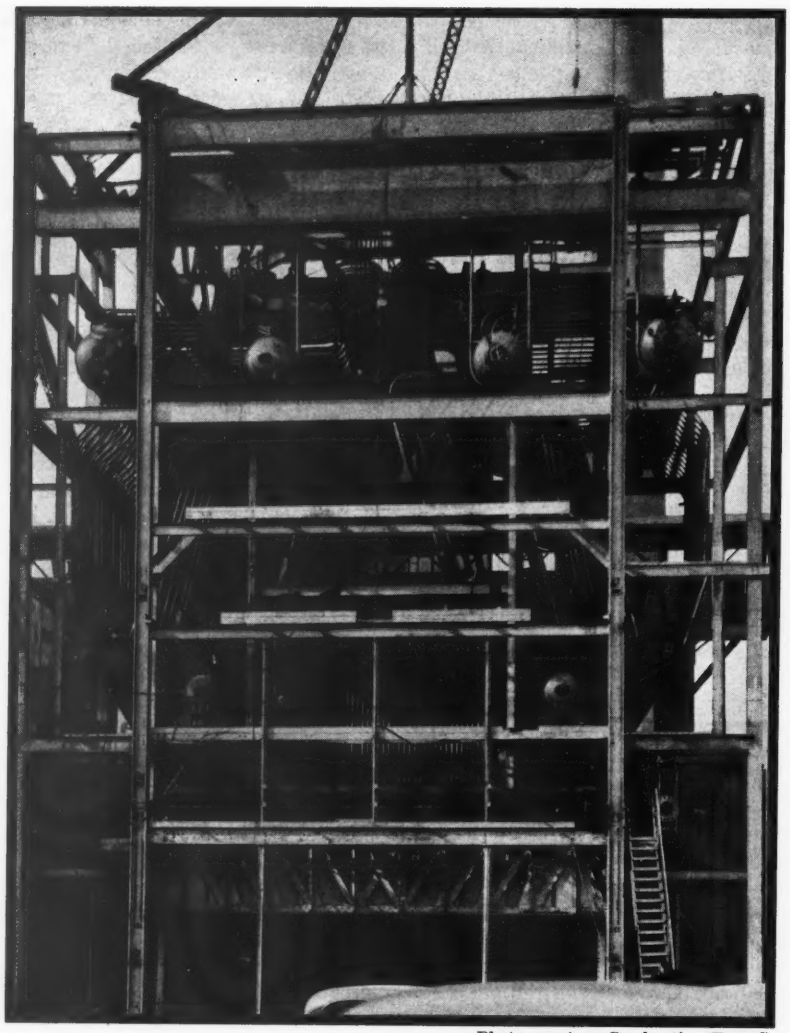


Photo courtesy Combustion Eng. Co.

Fig. 1. The complicated arrangement of the modern boiler is indicated by this construction view of the Logan boiler taken just before the end wall was closed. This unit delivers 1,000,000 lb. per hr. of steam to the turbine at 1250 lb. ga., 925 deg. F., and is of the pulverized coal fired, dry bottom type. Furnace volume 41,000 cu. ft.; waterwall surface 20,300 sq. ft.; boiler surface, 20,800 sq. ft.; superheater surface, 26,000 sq. ft., with bypass damper control; economizer surface, 25,850 sq. ft.; regenerative air heater surface, 90,400 sq. ft.

Evolution of the MODERN BOILER UNIT

Capacities to 1,000,000 lb. per hr., pressures to 2500 lb. per sq. in., tempertaures to 950 deg. F. outlines briefly the range of the modern American Boiler. Waterwalls and superheaters dominate all designs, with the boiler, economizer and air heater surface arranged to meet local needs which, in many cases, are set by existing building limitations, a characteristic of tops.

BOILERS for the low and medium pressure range as covered in a preceding section, have been more or less standardized as the result of many years of operating experience. They may be considered more or less independent of, or, at most, only slightly influenced by the method of firing and selected auxiliaries. Modern boilers or steam generating units, as being built for current high pressure, high temperature operation, are individualistic, designed for particular conditions of installation and operation with the method of firing, boiler, auxiliaries and appurtenances considered as a unit. About all they have in common is the ability to generate steam at high capacity and high efficiency from fuel burned in cooled furnaces.

No Standardization

These furnaces may be fired by stokers, gas, oil or pulverized coal. The cooled walls may be made up of tubes with welded fins to give a complete metal covered surface, by bare tubes spaced on varying centers to give different degrees of screening to the refractory walls, or by tubes covered by metal blocks or refractory. Pulverized coal ash may be removed dry, or in slag form continuously or intermittently.

The water cooled surface may constitute practically the entire steam making surface of the unit or it may be only a small fraction. The boiler surface proper may be straight, tube, bent tube, or any combination placed horizontally, vertically or at any angle. Superheaters, too, may be any shape or position, counter, parallel or mixed flow or even of radiant type. Economizers of bare or finned tubes may or may not be used. Air heaters are commonly used but may be of the plate, tube, or regenerative type, the latter being more numerous because the design facilitates crowding a large amount of surface in a small space, conveniently arranged.

Slow Development

Details of these different parts are covered in previous articles and this article will deal primarily with the evolution of the steam generator with typical examples of the latest practice. This evolution has been a long and tedious process. Hero of Alexandria was, by 130 B. C., familiar with the expansion and condensation properties of steam and the ability of an escaping jet to create a force both by impulse and reaction. This knowledge lay dormant, however, until the seventeenth century when a slow development of fire-engines or pumps began. This work led naturally to the steam engine but it was not until the invention of the separate condenser about 1765 that any appreciable progress was made.

Up to this time the boilers were spherical, or cylin-

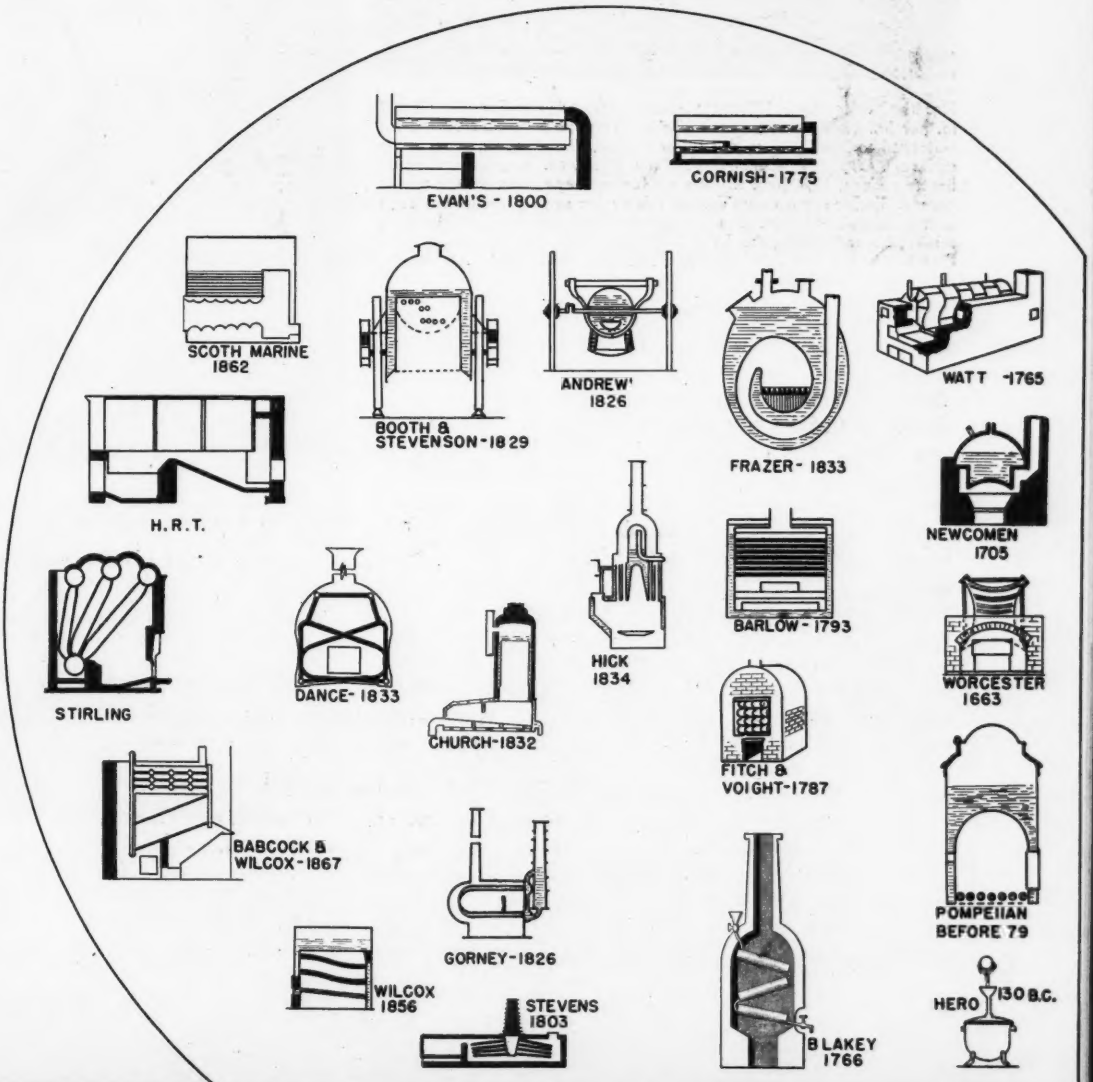


Fig. 2. For the past 150 yr. boiler development has followed two well defined courses. Many of the early designs displayed a great deal of ingenuity, some of which was an earnest effort to improve the performance and some just as earnest an effort to circumvent existing patents.

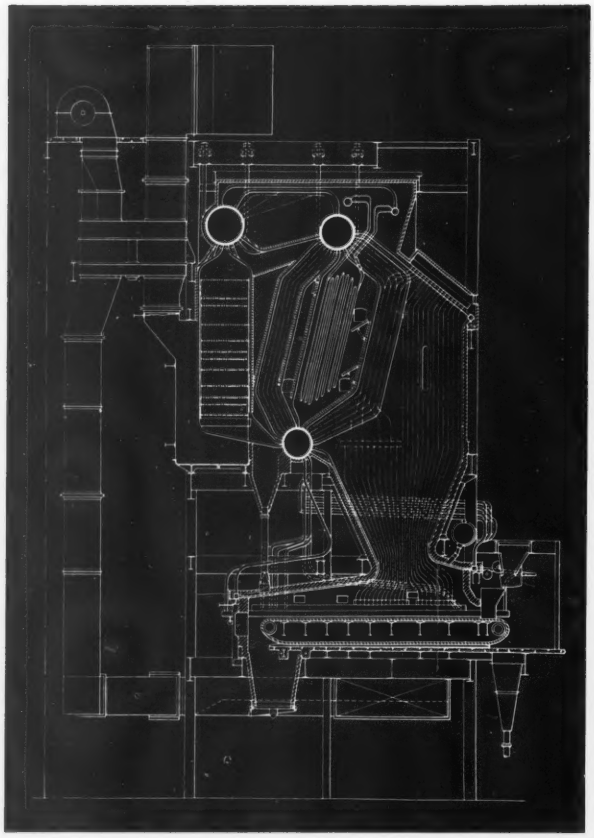


Fig. 3. Omaha uses a 570 sq. ft. chain grate stoker to fire this 255,000 lb. per hr., 1200 lb. 900 deg. F. boiler. Furnace volume, 9400 cu. ft.; waterwall surface, 3500 sq. ft.; boiler surface, 12,000 sq. ft.; superheater surface, 9700 sq. ft.; economizer surface, 18,100 sq. ft.; regenerative air heater surface, 12,300 sq. ft. Low ash-fusion temperature Kansas coal is burned. Earlier low pressure units in this station employed double stokers with a firewall between. The superheater is of the parallel flow type, screened from the furnace by a baffle and using bypass damper temperature control

drical, influenced greatly by contemporary brew kettle and chemical retorts design and construction, but the steam engine soon led to the introduction of designs more practical for producing a continuous supply of sizable quantities of steam. The Cornish boiler, internally fired, was developed about 1785 and, with its variations the Lancaster and Galloway, is still used today. The locomotive firebox boiler, essentially the same as built today, was used in Stephenson's Rocket in 1829. Evans used a single return flue in 1800, but the combination of an internal furnace and multiflues as in a Scotch marine did not appear until 1862. The horizontal return tubular is still more recent.

These changes were made in an effort to obtain increased heating surface, with corresponding output, from a given shell. Considered entirely apart from efficiency, the unit performance of these early units was satisfactory for Watt, who retired in 1800, used from 8 to 10½ sq. ft. of heating surface per cubic foot of water evaporated, over twice the rated output of modern fire tube boilers.

The water tube boiler in all its forms from the once through forced circulation to the porcupine, straight and bent tube types received as much as, if not more, attention than the fire tube, but practical designs were not developed until late in the nineteenth century. Circulation, which more or less took care of itself in the fire tube boiler, proved to be a stumbling block, and, to be fair to the early investigators, it may be mentioned that circulation is still a major problem, checked perhaps but not yet fully tamed.

Watt protested that higher pressures (above 1 or 2 lb.) "do not serve any good purpose" but the advantage, even necessity for, high pressure was recognized

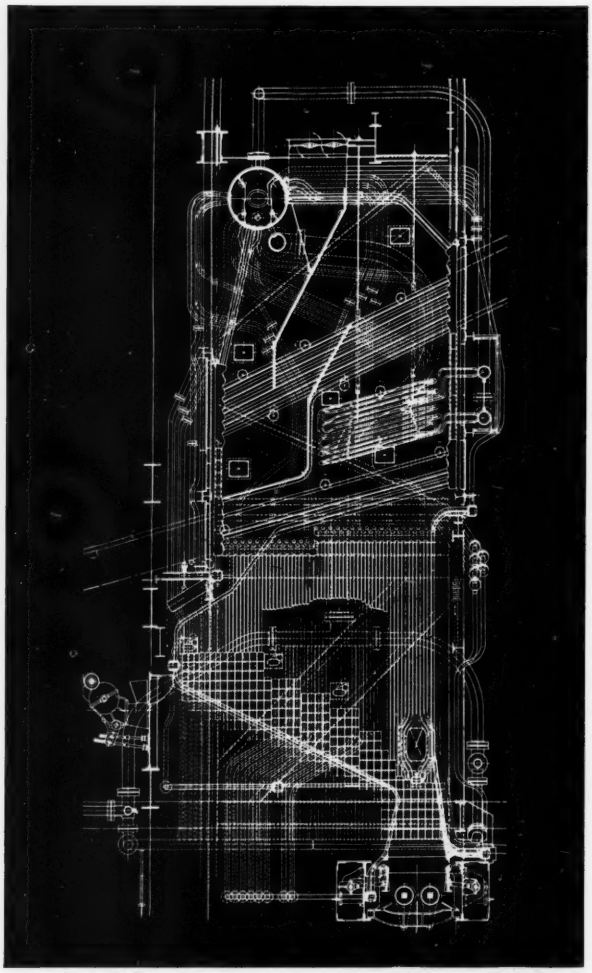


Fig. 4. Cedar Rapids pioneered the water cooled underfeed stoker. This boiler with a capacity of 300,000 lb. per hr. of 700 lb., 765 deg. F. steam is fired by a 545 sq. ft. stoker using Illinois coal. The furnace, with a volume of 7500 cu. ft., is divided by a center wall made of 3 in. tubes set on 3⅛ in. centers. Waterwall surface, 7137 sq. ft.; stoker cooling surface, 600 sq. ft.; boiler surface, 13,389 sq. ft.; superheater surface (parallel flow) 4533 sq. ft.; economizer surface 4608 sq. ft.; regenerative air heater surface 20,500 sq. ft.

early. Smeaton used 10½ lb. pressure in 1667, Trevithick was using 50 lb. by 1810, 150 lb. by 1814 and by 1825 had demonstrated the advantage of superheat. Perkins a contemporary was using 1500 lb. This line of development was, however, hampered by difficulties and was not followed up commercially for several generations.

From earliest times boiler development has been restrained by factors inherent in itself; lack of suitable materials and construction methods; inadequate data of the properties of water and steam; and a limited

knowledge of the fundamental factors involved. It is safe to say, however, that the most significant were external to the boiler itself. The four most important factors in modern boiler development have been: first, the creation of the central station industry with a major interest in the production of steam as a step in power generation; second, the introduction of the turbine to handle any pressure and temperature that available materials allow the boiler to be operated at; third, pulverized coal largely responsible for the successful application of the air heater and water walls; fourth, the extraction cycle which is a direct competitor of the economizer.

Larger capacities, higher pressures and temperatures resulted from the demands of the utility industry for lower first costs, better operation and higher cycle efficiencies. Development of chrome, nickel, molybdenum steel alloys and welding which plays such an important part in the present high temperature phase was the direct result of this demand, coupled with a parallel demand from the chemical industry and oil refineries. While a youngster, around 1820, Faraday of electrical fame, experimented with alloys of some 18 different elements and if his attention had not been directed elsewhere it is possible that the early work of Perkins might have been more productive of lasting results.

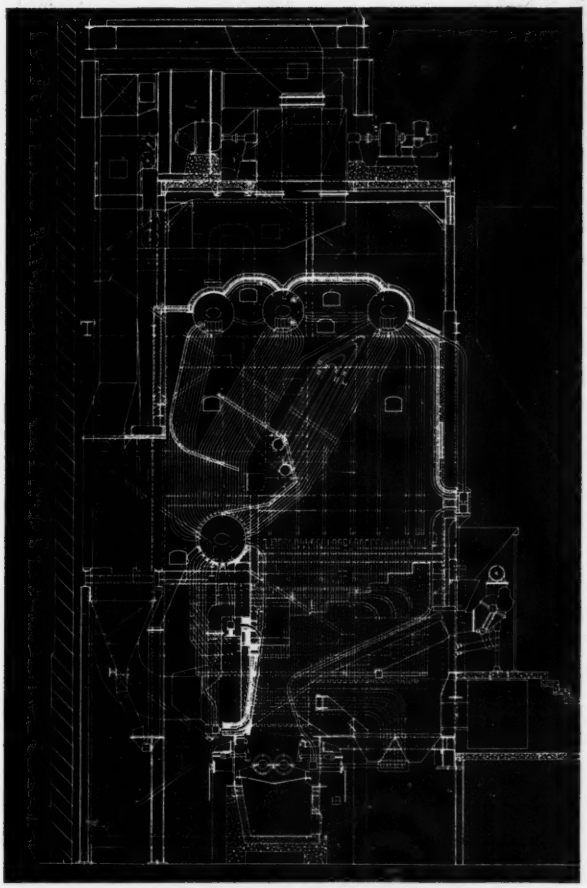


Fig. 5. The new unit at the Rochester (Minn.) municipal plant is designed for burning either natural gas or coal. The stoker is water cooled. Throttle conditions are 400 lb., 650 deg. F. and the boiler has a rated capacity of 125,000 lb. per hr. Waterwall surface, 1950 sq. ft.; boiler surface, 10,190 sq. ft.; superheater service, 1750 sq. ft.; regenerative air heater surface, 7000 sq. ft. The forced draft fan, induced draft fan and air heater are located at the top of the boiler

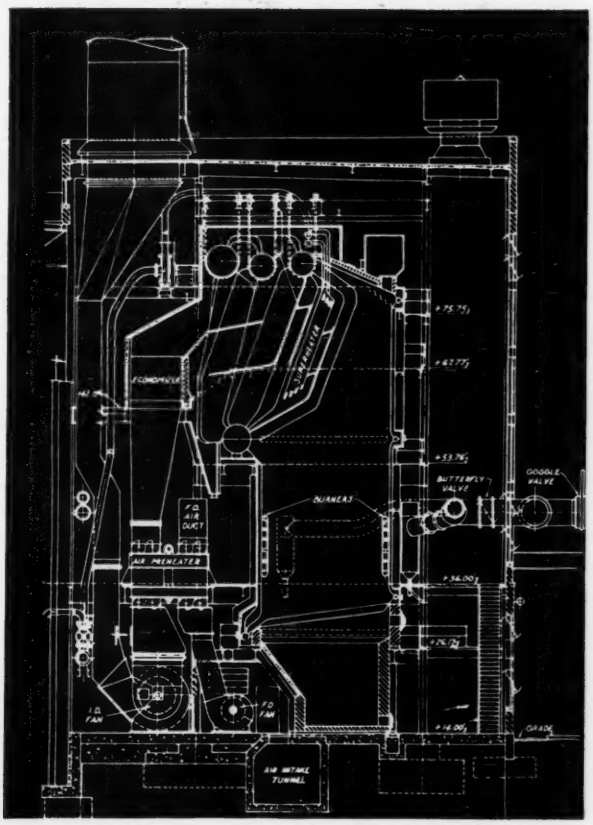


Fig. 6. Boilers at the No. 5 Plant, South Works of the Carnegie-Illinois Steel Co. burn blast furnace gas, natural gas or oil. The furnaces are fired tangentially to give a boiler output of 300,000 lb. per hr. at throttle conditions of 450 lb., 750 deg. F. The furnace has a waterwall surface of 5675 sq. ft.; a boiler surface of 22,000 sq. ft.; a superheater surface of 6450 sq. ft.; an economizer surface of 7180 sq. ft., and 52,400 sq. ft. of regenerative air heater surface. The boilers and building are designed for later changeover to pulverized coal

Although possessing inherent advantages which had been demonstrated practically as early as 1825, the superheater, like the early preheater, fought an uphill battle. Engines, the only steam prime movers available, could use but a limited temperature and that with difficulty. Like high pressures, the practical advantage of superheat was strenuously denied and it labored under the further handicap of fear that the steam would be broken down into its component parts. Slow progress was made however and both plate and tube superheaters were used to a limited extent from 1860. Because of the low temperature needed they were first located in the boiler uptake and acted as a reclaimer of waste heat. The turbine made way for the superheater and as temperatures increased it grew and moved up to the second pass of the boiler where hotter gases were available.

These developments focused attention on economy and favored the economizer. From the very nature of the boiler, the exit gases cannot be cooled below the saturation temperature of the drum so that increased pressures mean higher exit gas temperatures. Furthermore, as the gases cool in their passage through the boiler, the tail end surface is less effective, because of

the smaller temperature difference, and adequate surface to approach the limiting temperature is expensive.

The economizer solved this problem nicely. With a definite circulation and simpler design, the surface necessary to cool the gases could be added cheaper than a corresponding amount of boiler surface, and, that water flow could be made counter current to the gas so that the coolest gases come in contact with the coolest water so as to allow the gases to be cooled below the saturation temperature of the drum. In addition the economizer relieved the boiler of a considerable portion of its load. Feedwater from the open heaters, common at that time and using auxiliary exhaust, could be heated to 212 deg. F. Pumping this direct to the boiler meant the boiler had first to act as a water heater and then as an evaporator.

By taking over part of the load of water heating (not all of it for the early units were of cast iron and made no steam), the boiler was relieved of a considerable portion of its burden and efficiency was increased because the heating was done with what would otherwise have been waste heat. Although not fully appreciated at the time, circulation was improved for it is now recognized that heating of water in the boiler may seriously disturb natural circulation.

By the time of the world war boiler design was, therefore, fairly well standardized with the A.S.M.E. Boiler Code well established. Fire tube boilers occupied a definite position in the field because of their simplicity, low cost and good efficiency. They are still an important factor but, in spite of the fact that separate economizers and superheaters have widened their scope considerably, definite pressure limitations of about 200 lb. restrict their use to what is today the low pressure field.

The water tube boiler, built in bent and straight tube designs, had established definite leadership of the then high pressure field. Both the economizer and superheater had earned a definite recognition. Separate economizers were used with both types of boilers but the bent tube was more commonly built with the economizer integral with the boiler itself, with circulation more or less directed by baffles in the drums.

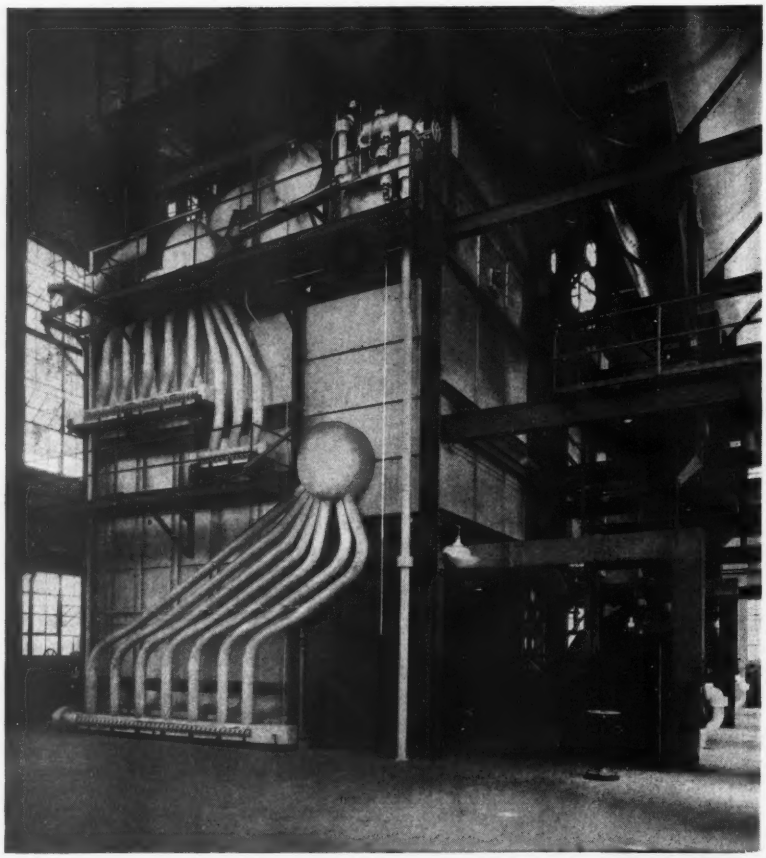


Fig. 7. Of recent years external boiler details have changed as much as the internal details. This recent installation at Seagram's new Louisville distillery shows a typical well designed industrial installation. The boiler setting is steel encased and the photograph shows the waterwall downcomers from the lower drum to the waterwall heater and the steam risers from the top of the wall to the steam drum. Coal hoppers, grates, spouts, chutes and feeders are all dustproof. Boilers operate at 400 lb. pressure and the furnace volume of 4400 cu. ft. is cooled by 1795 sq. ft. of water walls. Photo, courtesy Henry Vogt Machine Co.

In the light of subsequent developments it is probable that a progressive increase in operating conditions up to at least 1400 lb., 750 deg. F. would have caused no material alteration in the fundamental designs used at that time if external factors had not again interfered with the orderly development.

About this time pulverized coal and extraction feedheating came into prominence. The latter competed directly with the economizer and if carried out to its ultimate limit would displace it completely. For a period it seemed as though this would happen. The air heater, which like the early superheater had been waging a losing battle was available for taking over the job of waste heat recovery relinquished grudgingly by the economizer, and the preheated air was a great help, if not an actual necessity, for pulverized coal firing.

The economizer did not, however, pass from the pic-

ture completely, although it was considerably abbreviated. It is not practical to heat the feedwater up to full saturation temperature with extracted steam and boiler circulation requirements made heating over the entire range advisable, boiler feed pump operation at very high temperature proved troublesome and high pressure heaters to circumvent this proved expensive, and, the air heater had difficulty in handling the entire waste heat recovery with the high pressures and small boiler surface. The economizer, therefore, was retained in many cases but designed so that some steam may be produced at certain loads, the modern steaming economizer.

As far as the boiler proper was concerned these changes might have passed almost unnoticed if they had not been accompanied by corresponding changes in the furnace. High heat releases gave high furnace temperatures which caused high maintenance changes on solid refractory walls. Both air cooled and water cooled walls, neither of which was new at this time, flashed into prominence. In the ensuing development the water wall proved more adaptable and was rapidly

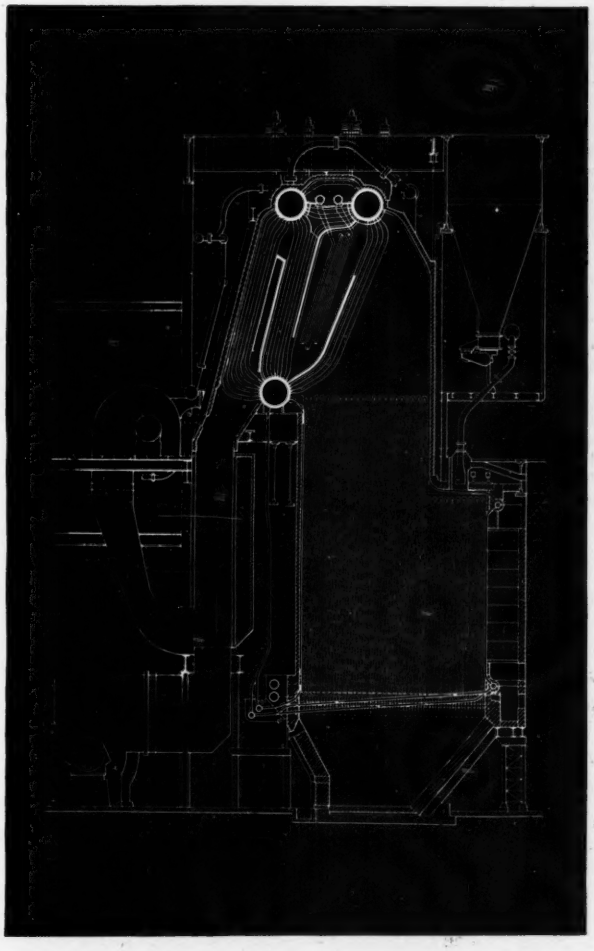


Fig. 8. Port Washington holds the world's record heat rate. The unit is fired vertically by pulverized coal and has 58,000 cu. ft. of furnace volume. The rated capacity is 690,000 lb. per hr. of 1300 lb., 830 deg. F. steam. Boiler surface, 44,087 sq. ft.; plate type air heater, 121,000 sq. ft. The combination superheater has 8700 sq. ft. of convection and 1464 sq. ft. of radiant surface on the back wall. The side walls have 1464 sq. ft. of radiant reheating surface and the balance of the furnace is cooled by 7996 sq. ft. of water walls

Fig. 9. One of the most recent industrial boilers, a 1250 lb., 825 deg. F., 300,000 lb. per hr. unit for the Dow Chemical Co. It is horizontally fired by pulverized coal and has a 15,200 cu. ft. continuous slag tap furnace. Water wall surface, 4900 sq. ft.; boiler surface, 3510 sq. ft.; superheater surface, 4950 sq. ft.; economizer surface, 27,000 sq. ft.; air heater surface, 49,900 sq. ft.

extended to the entire furnace. This fundamentally evaporative surface, serving the same purpose as the boiler proper, took over a large share of steam making and, as it is tied in with the boiler circulation, necessitated radical changes to take care of the circulation requirements.

In many of the newer units the water wall surface equals, and often far exceeds, the boiler surface. Increasing pressures still further minimize the importance of the boiler surface for the latent heat of evaporation decreases with pressure and becomes zero at the critical pressure. Thus in a steam generator operating at the critical pressure, the boiler section would disappear completely, leaving only two sections, an economizer and superheater.

Reheat also caused some disturbance at the same period but because it is more or less passive at the present time will not be considered in detail here. The earlier reheat plants used separate reheat boilers, made up largely of superheater coils screened by sufficient steam making surface to reduce the furnace gas temperatures to safe limits. Steam reheaters were tried but most of the stations turned to gas heated convection surface, preceding or parallelling the economizer surface. Most of these were for high pressure operation and the high cost of forged drums necessary at the time favored the use of the single cross drum,

straight tube boiler. The characteristics of convection superheaters and reheaters is such that the steam temperature decreases with load and to get adequate temperatures at part load large surfaces were installed.

Superheater alloys were available early to take care of the higher full load temperatures but the turbines were not constructed to handle it and temperature control was commonly maintained by thermostatically controlled desuperheaters in the superheater outlet. This was the start of the superheat control problem so important today and usually handled by dampers, which, however, are not new as they were used on the first high pressure top plant almost 15 yr. ago.

In contrast, the radiant superheater characteristics are such that the steam temperature increases as the load drops and a combination of radiant and convection superheater surface can be used to give constant steam temperature. Somewhat the same effect can be obtained by moving the convection surface closer to the furnace, that is screening it with a fewer number of boiler tubes. Radiant reheaters were also used to a limited extent as they fit in well with turbine operation at variable reheat pressures. Top plants using a constant reheat pressure match better with convection reheater characteristics.

Paradoxically enough, the phenomenal rise of pulverized coal did not discourage the stoker manufacturers but spurred them on to further efforts. The underfeed stoker particularly has been developed to the point where it is used in all sections of the country, burns quantities of coal undreamed of a few years ago and makes full use of waterwalls and preheated air. In the smaller boiler field the sprinkling stoker has made remarkable progress during the last few years and in all sections of the country.

This then was the position of the steam generator at the beginning of the present high temperature era. Air heaters, economizers and water walls were well established while dust collectors for preventing flyash discharge from the stack were used to some extent. For pulverized coal firing both the continuous and intermittent slag tap furnaces were well developed but the original dry type bottom was more common. Stokers had been developed to handle steam outputs comparable with pulverized coal.

Any trend toward standardization was, however, shattered by the advent of 850 to 950 deg. F. tempera-

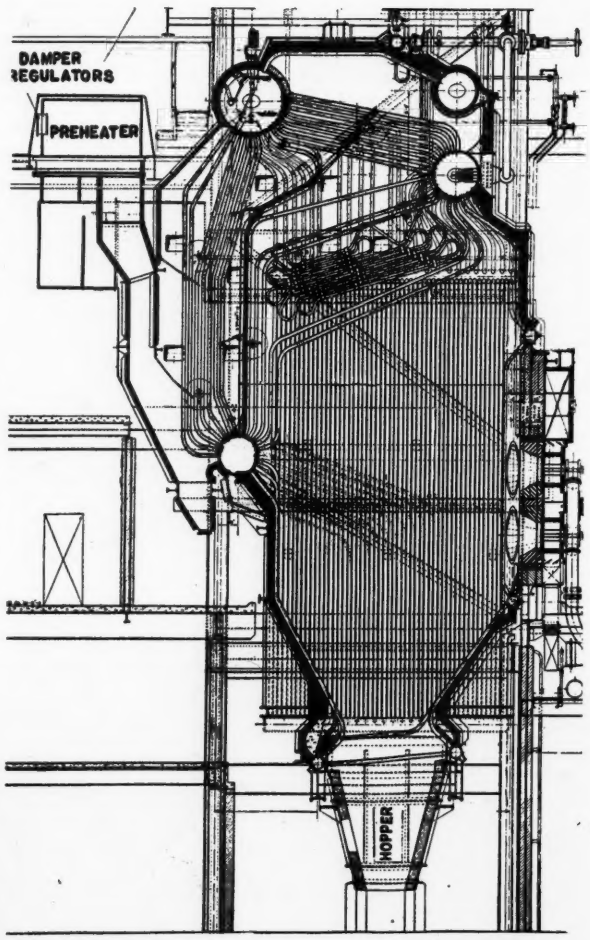


Fig. 11. The 430 lb., 810 deg. F. boiler at Lynn is fired with pulverized coal by horizontal burners and has a maximum capacity of 205,000 lb. per hr. Temperature control is by means of a desuperheater which can be seen in the forward drum. Superheat or final steam is controlled thermostatically by bypassing a portion of the steam through the desuperheater coils as explained in an earlier article. The furnace volume is 11,700 cu. ft.; water wall surface, 5660 sq. ft.; boiler surface 14,800 sq. ft.; superheater surface, parallel flow and screened by only two rows of boiler tubes, 2960 sq. ft.; regenerative air heater surface, 15,800 sq. ft.

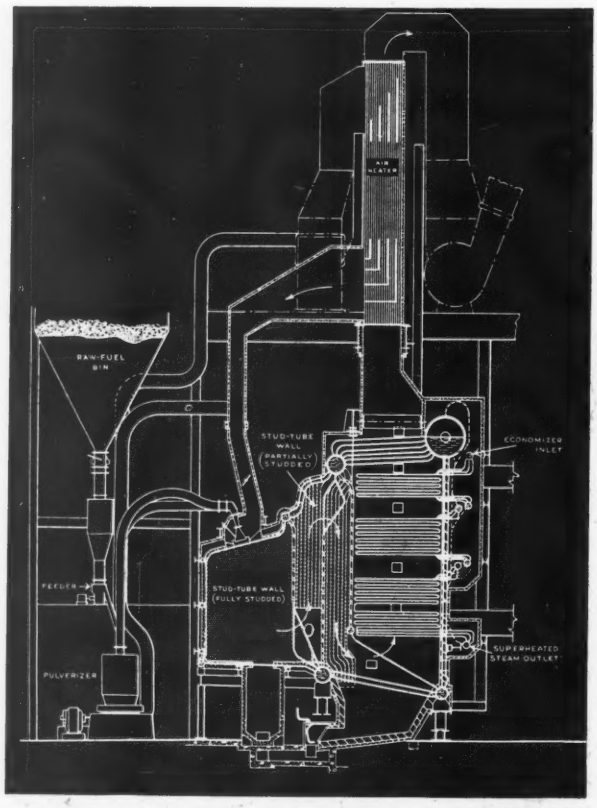


Fig. 10. West End is interesting because of the unusual construction adopted to get a large capacity in space limited by an old building. The boilers have a capacity of 350,000 lb. per hr. each at 1450 lb., 910 deg. F. The furnace with a volume of 4800 cu. ft. was designed for the unusually high heat release of 96,000 B.t.u. per cu. ft. per hr., over three times the usual value. The water wall surface of 7400 sq. ft. comprises practically the entire steam making surface and constitutes a so-called radiant boiler. The horizontal economizer has a surface of 15,000 sq. ft.; the counter flow superheater, 7400 sq. ft., and the tubular air heater, 34,800 sq. ft.

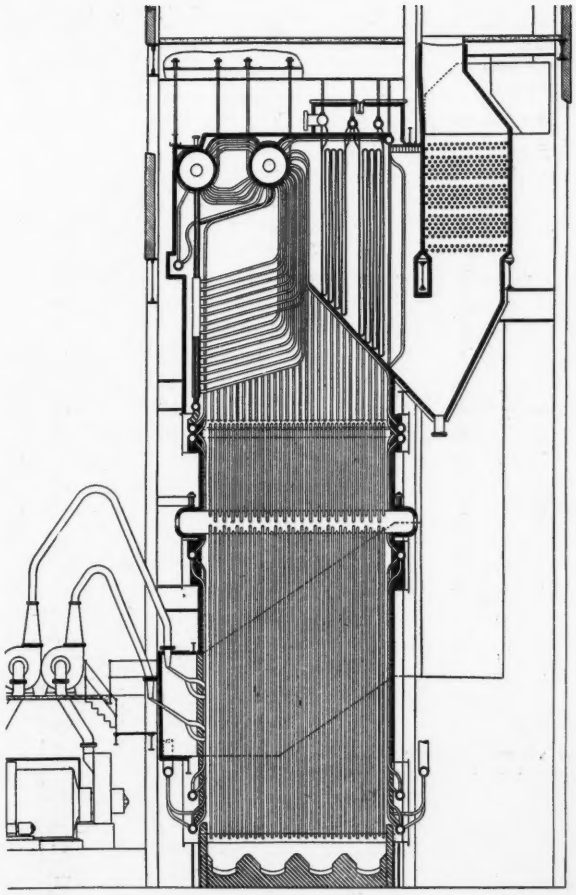


Fig. 12. One of the most unusual designs is the double furnace unit at Windsor. Capacity 750,000 lb. per hr. at 1525 lb., 925 deg. F. The 40,600 cu. ft. furnace is divided by a water wall screen, the total water wall surface being 7743 sq. ft. Boiler surface, 7717 sq. ft.; economizer surface, 34,800 sq. ft.; air heater surface, 47,800 sq. ft. The total superheater surface of 15,580 sq. ft. is divided between the two sides, the section on one side including 1530 sq. ft. of radiant surface (in one furnace only). Superheat control will be obtained by varying the rates of firing the two furnaces. This dry bottom furnace will operate in parallel with a slag tap unit of the same capacity. A section taken parallel with the drums is shown in an earlier article

tures which increased superheater requirements to such an extent that complete revision of boiler design was necessary. Each element of the unit, air heaters, economizers, superheaters and furnace is covered in separate sections earlier in the issue together with a table showing the significant data and area ratios of a number of the recent installations.

The trend of present practice is, however, indicated by an analysis of 100 large new boiler units made last year. This showed the following: 23 for 1200 lb. or over; 21 for 900 deg. F. or higher; 90 bent tube and 10 straight tube designs; 70 for pulverized coal, 10 of them for slagging bottoms; 47 with economizers; 86 with air heaters; 39 with both economizers and air heaters. It is probable that this proportion will hold approximately for some time to come.

In present boiler design, the load, the fuel and the method of firing fairly well determines the necessary furnace width. Pulverized coal fired boilers of the type installed at Logan and River Rouge may be designed for steam outputs as high as 35,000 lb. of steam per foot of furnace width. Stoker designers feel that these figures may be matched by stokers burning up to 70 lb. per sq. ft. of grate area per hour, lower than the present rate on the Hudson Avenue stokers at an output of 500,000 lb. per hr. Development of very large stoker units has been made possible by better control of the fuel bed by zoning as at Delray, wide stokers which have been employed successfully in Europe, by firing the furnace at both ends and by water cooling. The Cedar Rapids unit, Fig. 4, is one of the recent examples of the newly developed water cooled stoker, the furnace in this case being divided in two sections by water walls.

Particularly with middlewestern coals, the chain grate stoker played an important part and a recent installation of this type made with a high pressure boiler is shown by Fig. 3. Earlier chain grate units in the same station, Omaha, were made with twin units separated by a fire wall but it was felt stoker operation is now sufficiently reliable to warrant the use of the simpler single grate.

Of recent years the availability of natural gas in many sections of the country has caused increased use of this fuel for power purposes. Because of the method of delivery, and because dump gas is available at certain parts of the year or at low rates it is common to provide stand-by. Pulverized coal or oil work equally

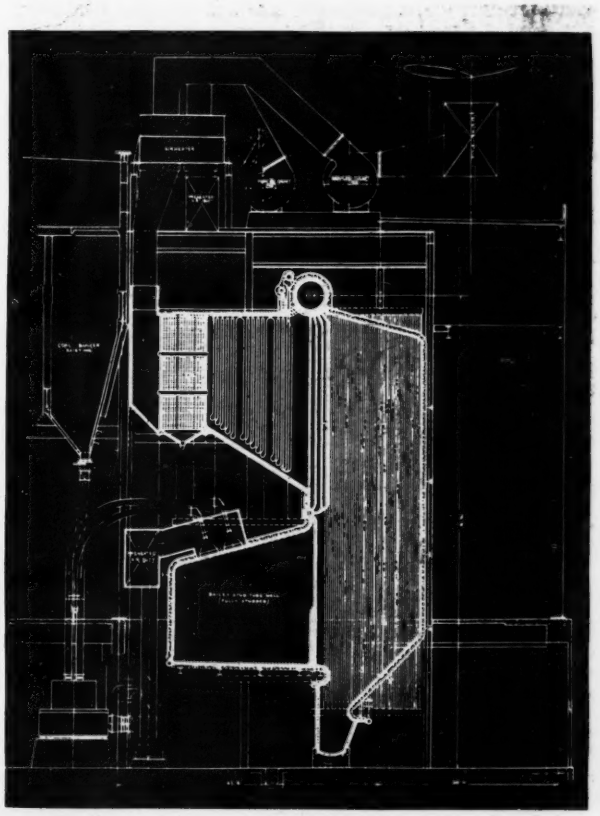


Fig. 16. Twin Branch is designed for the highest pressure used in this country, 2400 lb., 940 deg. F. The capacity is 550,000 lb. per hr. but the details are not yet announced. The furnace is of the two stage type as at Fisk and the secondary furnace walls will incorporate a radiant reheater. Both superheater and boiler tubes are vertical. This is the highest pressure yet used in this country and is felt to be the upper limit for natural circulation boilers. The station will operate on base load and its operating performance will have an important bearing on modernization of 600 to 800 lb. plants in the future

well for this purpose but the last year has seen the use of underfeed stokers for this purpose, the horizontal gas burners being installed by the Rochester (Minn.) municipal plant boiler, shown in Fig. 5. Figure 6 shows a gas and oil fired unit used in the steel industry, designed to use blast furnace gas, natural gas and oil with provision for pulverized coal later.

Fortunately, not all boiler design efforts are put on the inside. The outside too, involves careful consideration. Figure 7 shows the exterior of the Seagram boilers at the new Louisville distillery. The water-cooled walls are supplied with water by the downcomers which spread out from the lower drum. Circulation in the water wall tubes is upward to the heater and then out through risers to the upper drum at the left. The boiler is horizontally fired by pulverized coal.

Pulverized coal played an important part in influencing modern boiler development as explained earlier. This development was pioneered at Lakeside Station and the Port Washington boiler, Fig. 8, shows the latest construction of this company. Following past practice, the boiler is vertically fired through a short front arch. This unit is of further interest because of the use made of radiant surfaces in the furnace to give automatic temperature control. The superheater is of the combination type, the reheater all radiant. Radiant surface is also used in later boilers, Windsor, Fig. 12, and Twin Branch, Fig. 16.

Although the first pulverized coal units were vertically fired, to get a long flame travel and allow complete combustion, it was early recognized that turbulence was effective in shortening the flame travel. One of the early developments was the well type furnace in which a cyclone effect was obtained by firing tangentially from four corners of the furnace. The resulting high heat release resulted in high furnace temperatures which was utilized first at Huntley Station for removing the resulting ash in liquid form, the slag tap furnace. At first the slag was accumulated and the furnace tapped periodically. Later the continuous stage tap furnace was developed, slag being removed as it forms through a hole in the bottom. Slag tap furnaces may also be divided into the open and closed wet bottom types. In the first the furnace is open to the boiler surface. In the second it is screened, the result of dropping the slag screen lower and lower until it formed a distinct and definite type.

Waterside Station, shown on page 18, is a recent example of tangential firing and the open wet bottom or continuous slag tap furnace. Dow Chemical, Fig. 9, shows horizontal firing in an open continuous flow wet bottom, while Logan, Fig. 1, shows horizontal firing in a dry bottom furnace. The contemplated unit at Twin Branch, Fig. 16, shows the latest development of the closed wet bottom type into the two stage furnace. West End, Fig. 10, has the same type furnace but practically no convection boiler surface, a type known as the radiant furnace or boiler.

Because of the wide variety of new boilers no general conclusions can be reached either in regard to general or detailed design. Water walls of many types are in service: bare tubes with fins welded on to give complete cooling; bare tubes spaced on varying centers to screen the wall; tubes covered with cast iron blocks and with refractory. Economizers may have either plain or extended surface. Air heaters of the plate, tube and regenerative type are all used but the latter are more common in the newer units because of compact design which permits installing a large surface in small space. Convection superheaters are used almost universally with bypass arrangements for temperature control. Other methods of temperature control are being tried, however, and combination units have a sufficient operating background to offer an effective solution of the problem.

Fig. 17. Interior of a large boiler drum at one of the Detroit Edison Stations. The modern boiler designer gives a great deal of thought to proper introduction and distribution of feedwater and the separation of steam from the water and spray

FEEDWATER—
Treatment and Control

Adequate water treatment frees boiler designer from limitations set by scale and corrosion. High pressures and temperatures have not changed the basic requirements of feedwater treatment but have made exact application and control imperative

GOOD BOILER WATER should be non-scale forming and free from any tendency to cause corrosion, embrittlement, foaming, priming or carry-over. The trend of recent years toward high pressures and temperatures has not changed these basic requirements but has created new standards and made necessary a more scientific approach to the problem.

Calcium, magnesium, and to a limited extent aluminum, iron and zinc, in the form of carbonates, sulphates and silicates are the most troublesome from the standpoint of scale. Insoluble calcium carbonate and the more soluble magnesium carbonate precipitate to form sludge or mud which is not scale forming unless cemented together with sulphates or silicates which even in small quantities act as a binder to form a hard adherent scale.

Scale

Scale in reasonable quantities was formerly tolerated, sometimes even considered advisable, because it gave some protection against corrosion and meant only a slight loss in efficiency. With the advent of high pressures and high rates of heat transfer this condition changed for scale formation is the cause of excessive localized metal temperatures and early failure. This is so thoroughly appreciated that when scale forming waters have to be used, the problem is immediately put up to an experienced and competent feedwater chemist for solution.

As a result scale prevention as a feedwater problem has been practically eliminated by intensive and scientific research. Except in occasional cases where silicates or excessive condenser leakage is encountered, the chemical and physical factors of scale formation and prevention are well understood and under control. This complete elimination of scale, together with the faster chemical reaction at high temperatures, has, however, intensified the problem of corrosion which will be discussed later.

In general the modern boiler plant uses both external and internal chemical treatment augmented by thermal and mechanical means to achieve the desired result in the cheapest way. Makeup can be held to a minimum by utilizing returned condensate wherever possible, and in condensing plants where the makeup is normally low, evaporators are used extensively. Deaerators, too, have found wide application as a means of corrosion control. It has, however, been demonstrated that high pressure boilers may be operated successfully on 100 per cent makeup chemically treated.

External and Internal Treatment

Natural waters carry more or less mud, sand, chemical and organic matter, much of which can be removed before treatment by simple sedimentation or filtering. Subsequent chemical treatment is then necessary to remove temporary and permanent hardness and neutralize acidity or excessive alkalinity. External treatment aims at the removal of harmful solubles from the water in the form of precipitates or converting them into a less harmful form which after concentration in the boiler may be removed by deconcentrators or by blowdown.

This external process is sometimes complete in itself or sometimes used as pretreatment for reducing the cost or complications of final treatment in the boiler itself. Internal treatment is intended to prevent adherent scale formation by maintaining a definite balance of certain chemicals, or by colloidal action; to prevent embrittlement by maintaining definite chemical relations; and to prevent corrosion or carryover.

Zeolites

The Zeolites and the lime-soda ash softeners are the two most common external treatments. In the zeolite softener, built something like a pressure filter, raw water passes through a bed of natural or artificial material called zeolites which possess the property of substituting sodium for calcium and magnesium in the water being treated. When used up the zeolite sand may be regenerated or brought back to its original effectiveness by a solution of salt.

The treated water then contains non-scale forming salts of sodium. Some of this is in the form of sodium bicarbonate which breaks up, when heated to CO_2 and sodium carbonate so that the water should be heated in an open or deaerating heater to release the CO_2 before it enters the boiler. Sodium carbonate has the further disadvantage of breaking up under conditions in the boiler to sodium hydroxide and CO_2.

In the presence of silica particularly, and under certain conditions of metal stress, sodium hydroxide causes embrittlement unless inhibited by the presence

of sulphates. With natural water too low in sulphates to maintain the necessary ratios, the zeolite softened water may be treated with sulphuric acid to reduce the sodium carbonate content, or the raw water may be pretreated with lime to remove the temporary or carbonate hardness. Calcium bicarbonate and magnesium carbonate treated with lime forms an insoluble precipitate which may be filtered out before the zeolite softener is reached.

A very recent development is the so-called acid zeolite by which calcium, magnesium and sodium in the raw water are replaced by hydrogen. Used alone or with the other type of zeolite and followed by deaeration, it greatly increases the scope of zeolite treatment to handle waters of any hardness, remove scale forming compounds, reduce total solids and control alkalinity to maintain the desired sulphate-carbonate ratios. In fact preliminary work with various synthetic resins in removing ions and anions from solution has been most promising. It is said that solids in city water were reduced from 33 to 1 part per 100,000 by treatment with tannic and aniline resin in series, and that salt can be practically removed from sea water.

Hot Process

The hot process softener is used for removing both temporary and permanent hardness. Soda ash, caustic soda or lime, and a coagulant such as alum or sodium luminate are the chemicals usually employed. The soda ash removes the permanent hardness, the lime or caustic soda removes the temporary hardness and the coagulant forms a floc which assists in clarification and filtering. Reduction of sodium alkalinity for embrittlement protection when there is an excess of sodium bicarbonates in the raw water can be accomplished by feeding calcium sulphate with the lime.

The lime-soda ash process can be carried out cold, but the reactions are much slower and as feedwater must eventually be heated anyway, the hot process is more common in power plant work. In addition to speeding up the reactions the heat assists the chemicals in reducing the temporary hardness and as an open heater can be used the CO_2 and oxygen can be eliminated to a large extent.

In the intermittent or batch process, a definite quantity of chemicals are added to a known quantity of the water to be treated. In the continuous process, the chemicals are fed continuously or in small quantities in proportion to the flow of water. Chemicals other than those mentioned above are sometimes used to meet unusual conditions, usually, however, at greater cost.

Filters

In a properly designed and operated external treatment system over 90 per cent of the insoluble or suspended matter can be removed by gravity in the coagulating tank. The balance must be removed by filters. Cold process softeners may be sand or gravel but hot process softeners must use a non-siliceous material because silica, objectionable in a boiler water, is soluble in hot alkaline solutions. Material collected on the filter is periodically flushed to the drain by backwashing. This should be done with a sufficient flow to give some expansion to the filter bed so as to grade it for effective filtering, yet not carry off the fine material forming the top layer. Backwash velocities sufficient with cold water are not effective with hot water due to the decrease in viscosity.

Internal treatment, both with and without external pretreatment, has advanced rapidly of recent years, the rate of progress being dependent to a large extent on the development of test methods necessary for control purposes. Colloidal treatment is being used effectively for internal treatment and combines a slight chemical reaction with the formation of a spongelike gel which entrains scale forming precipitates and keeps them from adhering to the heating surfaces.

Various organic materials have been used for this colloidal action for a generation or more, but it is only of recent years that the colloidal action has been studied thoroughly and made susceptible to accurate control. The glucosides and their derivaties form one branch of the group. Pyro glucosale is effective in preventing sulphate deposition at low alkalinities and beta glucoside in preventing silica scale using a silica-chloride control ratio.

Chemical Ratios and Concentration

This matter of chemical ratios came into prominence with a realization of the necessity for protection against caustic embrittlement. As the result of extensive research, which is not yet completed, it was discovered that sodium hydroxide would, under certain conditions, cause intercrystalline cracks, but that this action could be inhibited by adequate sulphate contents. The effectiveness of this treatment depended upon the formation of a protective coating. The A.S.M.E. Code committee first made definite recommendations regarding relative ratios in 1925.

Later investigations disclosed that embrittlement was influenced by the presence of other salts principally soluble silicates. It was also determined that test specimens subjected to torsion, in contrast to tension, were not protected by sodium sulphate in either solution or solid form. This finding led to the conclusion that

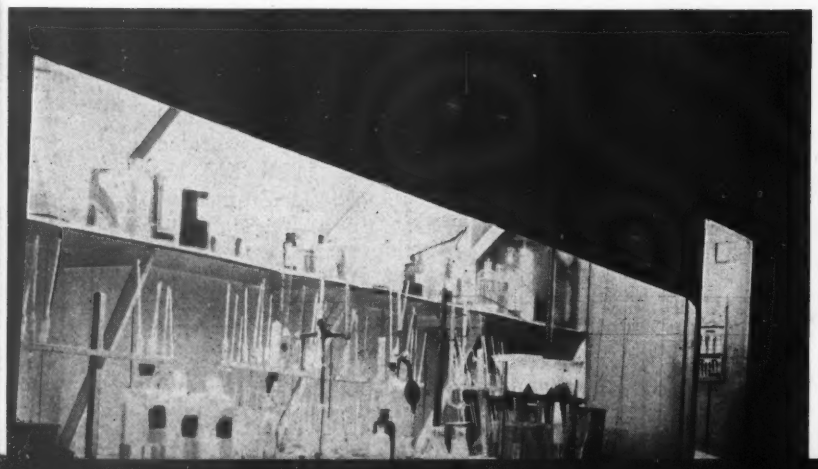


Fig. 1. Not every power plant engineer can be a feedwater specialist but every plant should be equipped with facilities to make simple tests necessary for adequate treatment control

effective protection in this case must lie in some form not susceptible to cracking, possibly by the formation of monomecular film on the metal surface. It was found that oxydizing agents appear to be equally as effective as sodium sulphate for protecting specimens stressed by straight tension.

In addition to organic materials soda ash, sodium aluminate and phosphates are widely used for scale prevention in internal treatment. Their use depends upon converting the scale forming salts to a non-scaling form or maintaining definite ratios of various salts to prevent the scale being formed. One method depends upon the maintenance of a phosphate to sulphate ratio which varies with operating conditions.

The maintenance of definite ratios must be made with due consideration to corrosion and the influence of concentration on carryover. The latter may cause trouble from deposits forming in superheater tubes and on turbine blades. Sodium hydroxide has been determined as a basic material in blade fouling and that sufficient organic salts such as sulphate, chloride and carbonates, or inorganic salts such as pyrogallol, sodium benzoate and sodium gallate may be used as a preventative.

Carryover is involved with priming and foaming which in a mild form has been prevented by mechanical means such as separators and scrubbers as explained in an earlier article. Foaming tendencies increase with high boiler water alkalinities but decrease with higher pressures. The tendency to foam depends not only on the composition of suspended matter but upon the physical state in which it exists. For example, magnesium hydroxide in an amorphous form or finely divided crystals has been found to produce foaming while having the opposite effect in larger sized crystals. Precipitation of certain salts inside the boiler has had the same effect, probably because of the large crystal formation, while precipitation outside of the boiler with subsequent introduction to the boiler water caused foaming.

Priming, the carryover of considerable quantities of solid water, is influenced largely by the design of the boiler with restricted steam liberating areas, and swell, the sudden increase of total water and submerged steam bubble volume with increases in load sufficiently sudden to cause the generation of large steam quantities from heat stored in the water.

This whole problem is tied up with concentration control of the boiler water which is handled in two ways. With deconcentrators a portion of the boiler water is withdrawn continuously and the solids removed by gravity or by filtering and the clear water returned to the boiler. When blowdown is used, the concentrated boiler water drained to the sewer is replaced with fresh water. Continuous blowdown is often used so the heat content of the hot water may be more easily reclaimed by the incoming feedwater.

Corrosion in boilers, pipe lines and steam using equipment is a major problem at higher temperatures. In the past emphasis has been placed on dissolved oxygen as a significant cause of corrosion but CO_2, particularly when in solution, is also an important factor. Corrosion rates are also increased by the presence of other factors such as hydrogen, sulphite, chlorides, sulphates, metals less active than iron and by the pH value of the water. Present practice seems to indicate a boiler water pH value of about 11 as effective in inhibiting corrosion, although pH control alone is not always a successful preventative.

Dissolved gases can be eliminated or at least reduced to ordinarily negligible quantities by the use of

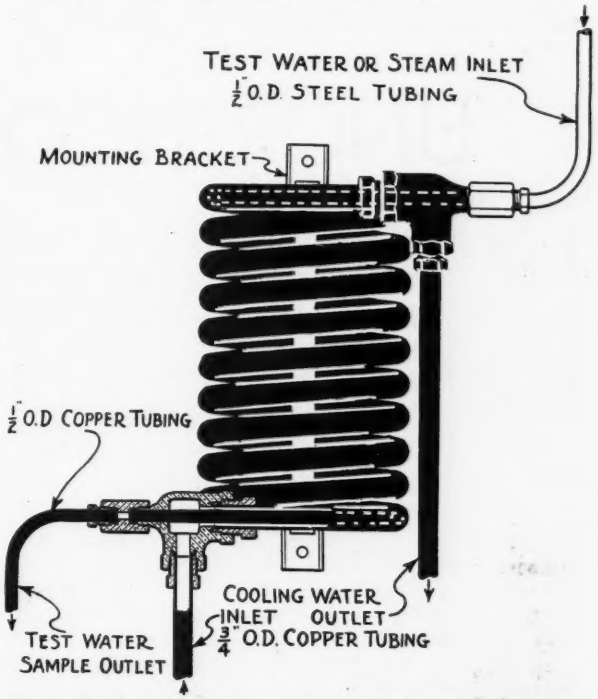


Fig. 2. The basis of boiler water control is reliable samples for chemical analysis. Hot boiler water released suddenly to atmospheric pressure flashes and a portion is lost as steam. The water should be cooled in a coil like this under pressure. Containers should be clean and the contents exposed as little as possible to the air. The test water should be drawn at the rate of about a quart a minute and the container allowed to overflow a considerable length of time to remove all air before being sealed and delivered for analysis

deaerators, designed to eliminate entrained gases by heating the water to the saturation temperature and splitting it up into fine sheets or spray to enable the gas to escape easily. In high temperature installations where complete removal of oxygen is necessary chemical deaeration is used to remove the last traces. Many methods have been suggested soluble ferrous salts, sodium sulphite and sulpho glucosate have proved effective.

Evaporators play an important part in the modern plant and have been used effectively not only in central stations but in industrial plants where large quantities of non returnable process steam is used as well. In central stations or condensing plants where condensate returns are available evaporators are commonly used to supply make-up. In industrial plants they are sometimes used as heat transformers, generating low pressure process steam and returning the clear condensate to the boiler feed system. Inasmuch as evaporators serve the same function as boilers, the feed is subject to the same requirements and is often treated.

Boiler water treatment is, as yet, definitely an art, susceptible to control as a result of experience but requiring continued observation and correlation of operating data before definite rules relating to treatment and operation can be made.

We are greatly pleased with our new Winton. From the very start it has done its work and never failed us. There may be improvements yet to come even in such autos, but it is difficult to see much room for them.

Andrew Carnegie, 1905

UNORTHODOX BOILERS

IT IS NEEDLESS to comment on the above quotation from Andrew Carnegie, here. We present it merely to show the vision of the great steel manufacturer at least as far as the automobile industry was concerned; it reflects no particular discredit upon Carnegie's foresight since it is only typical of the limitations of the human mind in all its operations, but at the same time we can well profit by the lesson it teaches. Whenever we hear somebody, especially somebody of note, make some eloquent statement about the perfection of an art or a device or any product of human endeavor it behooves us to be somewhat skeptical. Our universal inability to see very much farther than the end of our nose, so to speak, has only too often led us into embarrassing situations which from the point of hindsight could have been avoided.

In the preceding pages of this issue we have considered modern boiler development in all its aspects. It was shown to be a highly developed art. We have attained enormous sizes and high ratings. Efficiencies are high and in our best installations we have obtained degrees of reliability that were undreamed of in earlier days. We are using high pressures and temperatures with an easy confidence that invariably comes with thorough understanding and knowledge. Except as metallurgical limitations prevent our use of still higher temperatures, there is hardly any problem in steam generation beyond our capacity to solve. To a certain extent the trend of future progress in America seems established.

Orthodox vs. Unorthodox Developments

As implied in the introductory paragraphs, however, we must not accept this state of affairs in the boiler art with any degree of finality. In attaining this state of the art we have proceeded in a perfectly characteristic evolutionary way. We have assumed that we wanted to take as few steps into the unknown as possible. Our advance has been slow, along definite, what might be termed orthodox, lines. As problems came along they were solved or avoided but usually we did not go out of our way to find new ones. We met trouble as it came but we did not deliberately set out to look for it. We have been strictly conservative.

In putting it this way no criticism of this policy is implied; certainly it has been successful and because of our large scale operations and in view of our vast fuel resources, was undoubtedly the logical one for American engineers to pursue. At the same time it is desirable to investigate practices in other countries not so favorably situated as we are in regard to fuel resources and where a more stringent economy leads to the use of methods which in many ways differ radically from ours. While low pressure boiler practice in Europe has developed along lines much the same as ours, their high pressure technique has moved along different but equally characteristic lines. There engineers endeavored to analyze in advance all the factors which might be expected to enter the problem and then to produce designs which would properly take account of these new factors. They anticipated certain difficulties as a result of such analyses and then set out to avoid them. Thus, J. V. Blomquist of Stockholm anticipated difficulties in the heat transfer between metal and water, difficulties from the small volume of high-pressure steam and difficulties from cost of equipment depending upon the conventional method of heat transfer.

So he adopted a rotating boiler tube with provision for most intimate forced contact between water and boiler. He also obtained plenty of surface through which the steam might separate itself from the water, and an artificial separation through centrifugal effort as well. This development he introduced to the public in 1922 under the name of the Atmos boiler.

So, also, in 1922 Mark Benson in England attempted a unique solution by going to the sensational boiler pressure of 3200 lb. per sq. in. and making his boiler proper nothing but a water heater without drums or steam space. His boiler was merely a coil of small-bore steel tube which would stand almost any pressure up to 10,000 lb. per sq. in.

It was the general opinion, until a few years ago, that steam generation in narrow-bore steel tubes was not practicable because of ebullition troubles. Benson, therefore, adopted the remarkable method of heating water, maintained at a pressure of over 3200 lb. per sq. in. in a coil of tube by means of a force pump until the temperature was high enough to cause the change from water to steam to take place bodily under critical conditions.

Hartmann at Cassel, Germany, adopted still a radically different solution. His boiler consisted of two boilers operating at two different pressures. The boiler operating at the higher pressure is filled with distilled water, which never leaves it except through unavoidable leakage. This water is converted into steam and is then condensed in coils immersed in water contained in the lower pressure boiler, the condensate running back automatically to the boiler in which it was made. The distilled water then serves merely as a heat transferring device and protects the surfaces exposed to the fire from the

effects of scale deposition. These ideas have developed practically in what is now known as the Schmidt-Hartmann boiler, a number of which are in use.

The Loeffler boiler is still different. This boiler, developed by the Witkowitzer Bergban and Eisenhutten G. of Czechoslovakia, makes use of the principle of generating steam by blowing very highly superheated steam into water. This saturated steam is passed through a separately fired superheater equipped with an air preheater and economizer to obtain high efficiency of the combustion part of the cycle and with a regenerator to obtain high efficiency of the prime mover. Part of the steam which is superheated goes to the prime mover, and the remainder is returned to the water containing drum to keep up the production of saturated steam. It is obvious that this superheated steam would not flow back into the saturated steam drum because of the pressure loss in the system, so positive circulation of the steam is obtained by means of a centrifugal or reciprocating steam pump.

Combustion Under Pressure

Still another and radically different system from any of these referred to is that employed in the Velox boiler developed by Brown, Boveri and Co., of Baden, Switzerland. This boiler makes use of combustion under pressures of from 15 to 30 lb. per sq. in. and a gas turbine for operating the air compressor supplying the air for combustion. Very high velocity of the combustion gas is obtained by this system, velocities of around 650 ft. per second, which increases the heat transmission in the narrow bore steam-generating tubes which are arranged in vertical coils around the inside of a vertical cylindrical combustion chamber. Enormous rates of heat release are attained, in some cases as high as 890,000 B.t.u. per cu. ft. per hr. and efficiencies from 92 to 95 per cent are claimed.

The Russian Central Boiler Institute also has been engaged in developing furnaces for operation under pressure but so far as is known, no practical units have been produced. In a furnace, in some respects similar to that of the Velox boiler, with a pressure of 58.8 lb. per sq. in. they obtained combustion rates of 900,000 B.t.u. per cu. ft. per hr.

Another Russian development is the Ramsin boiler. This is a forced circulation boiler of the "once through" type which, according to reports has proved quite successful. The 1937 power project of Soviet Russia in fact provided for new construction aggregating 1,300,000 kw. capacity, of which the greater part was supplied by Ramsin boilers operating at 2000 lb. pressure and at from 900 to 932 deg. F. total steam temperature. Although several Continental designs, such as the Velox and Loeffler, have been used and investigated, the Central Boiler and Turbine Institute has developed its plans around the Ramsin design.

All of the steam generators listed above, it will be seen, differ radically from anything we have used practically in the United States, and all of them may be classified as boilers of the unorthodox type. There are a number of others, the La Mont, the Sulzer mono-tube, the former invented in the United States but now being developed in Great Britain, which employ principles similar to some of the others described but enough has been presented here to show the differences in trends between America and Europe.

One other European scheme should be presented, however, because of its revolutionary character even with respect to these, and that involves various methods of submerged combustion such as used in the Brumler steam generator. The idea is not new, the development extending from the patents of Collier in 1887, but its practical development has never attained any degree of success in the power field. As the name implies, in submerged combustion the flame resulting from combustion of the fuel is introduced below the surface of the liquid and heat transfer takes place by direct contact of the liquid and the products of combustion.

The Mercury Cycle

An outstanding example of American unorthodox boiler development is that of the mercury boiler, carried on under the direction of Wm. Le Roy Emmet by the General Electric Co. Even the mercury boiler, however, except for the different medium used, is quite conventional. It incorporates no fundamentally new ideas, except those which arise as a consequence of using so different a medium as mercury. Later developments indicated the need for unusual types of boilers, but essentially the principles involved in the mercury boiler are exactly those involved in the steam boiler. The mercury cycle is fundamentally an attempt to take advantage of the greater economy obtainable by the use of a wider temperature range in the thermal cycle, without the necessity of going to high pressures.

A boiler employing the "once through" principle which has achieved commercial development in this country is the Besler boiler. This boiler is of the continuous flow, water tube, forced feed, non-water level, counterflow type, having no drums, headers or storage tanks.

Steamotive

Finally, in this brief discussion of unusual boilers, mention must be made of the so-called "Steamotive" development through the joint efforts of The Babcock & Wilcox Co., The General Electric Co. and the Bailey Meter Co. This involves a special boiler of the oil fired forced circulation type operating at a pressure of 1500 lb. and 900 deg. temperature and completely automatic in its operation.

So much for a brief treatment of these schemes. In the pages that follow more complete descriptions of them will be presented. As was pointed out in the first article of this issue, whether these new schemes point the way to the pattern of boilers which will be used in the future or whether the present American types will survive, it is impossible to say, but they deserve all the study and consideration we can give them. At least they attempt to break away from the traditional and that is a healthy attitude. The difficulties in the way of radical advances in any line of human endeavor are chiefly two: first, our inability to throw off traditional patterns of thinking or reasoning which we have acquired through years of experience, and secondally, the difficulty of taking hold of anything fundamental that is so completely simple that nothing sticks out from it to offer a handhold. The more familiar an "accepted truth" the harder it is to dispute or modify or doubt. Yet that is precisely what we must do if we are not to remain content with what we have inherited from the dead inadequate past.

MERCURY-VAPOR BOILERS

THE MERCURY VAPOR BOILER was developed in order to achieve a greater thermal economy in the production of power from fuel than is found possible in the use of the steam cycle alone. As pointed out in the other articles in this issue, the economy of any thermal cycle is a function of the temperature range involved, and since the lower temperature of any heat cycle is usually fixed by the temperature of the condensing fluid, the only way the economy of a given cycle can be materially increased is by increasing the upper temperature limit.

The temperature of water boiling at atmospheric pressure is 212 deg. F. With increasing pressures, the temperature of the boiling point is raised. At 10 lb. gage it is 240 deg., at 40 lb., 287 deg., and so on. The highest pressure at which water vapor can exist, however, is 3226 lb. per sq. in. and at that pressure the temperature is only 706 deg. F.

With mercury, saturated vapor can be obtained with low pressures and with much higher temperatures than is possible with steam. It is this fact that led early investigators to consider the possiblity of using mercury as the working fluid in boilers in place of water. With a pressure of only 70 lbs. per sq. in., which was the pressure used in the first commercial mercury vapor boiler at Dutch Point Sation near Hartford, Conn., the temperature of the mercury vapor is 884 deg. F., a temperature far higher than could be obtained with saturated steam even at the critical pressure, i. e., 3226 lb. per sq. in.

The mercury vapor boiler is used in what is known as a binary system, that is, a system using two fluids or two vapors. The other vapor is steam. The mercury vapor, generated in a special boiler, is sent through a mercury vapor turbine from which it exhausts into what may be called a condenser-boiler. Water passing through this condenser boiler is turned into steam by the latent heat of the mercury as the latter condenses and this steam can then be used for power as at Hartford or for heating, or as in the case of the more recent mercury vapor installation at Schenectady, or for both power and heating. In the mercury cycle all the latent heat of the mercury vapor is used to generate steam at any desired pressure. The mercury cycle can thus be considered as a steam producer, where a large amount of power can be obtained from the mercury vapor at practically theoretical rate, and the amount of steam produced is only slightly less than that produced by a steam boiler for the same amount of fuel.

This advantage holds for all pressures and temperatures, though the advantage decreases as the high temperature limit of the steam cycle to which it is compared is raised. As long as comparatively low steam pressures and low superheat were used in steam cycles, the mercury cycle offered a very substantial advantage, since high temperatures could be obtained without high pressures. The temperatures provided by the mercury cycle were well within the limits at which the steels used in the boilers and turbines could be operated.

With the advent of high pressure and high temperature steam operation, however, the advantages which the mercury cycle offered over steam decreased and today with boilers operating at 1200 and 1400 lb. and with total steam temperatures of over 900 deg., the thermal economy of our best steam stations closely approaches that of the mercury cycle.

This does not mean that all the advantages of the mercury cycle disappear when the steam temperatures are pushed up to those which hold for the mercury vapor temperatures. The efficiency of the mercury

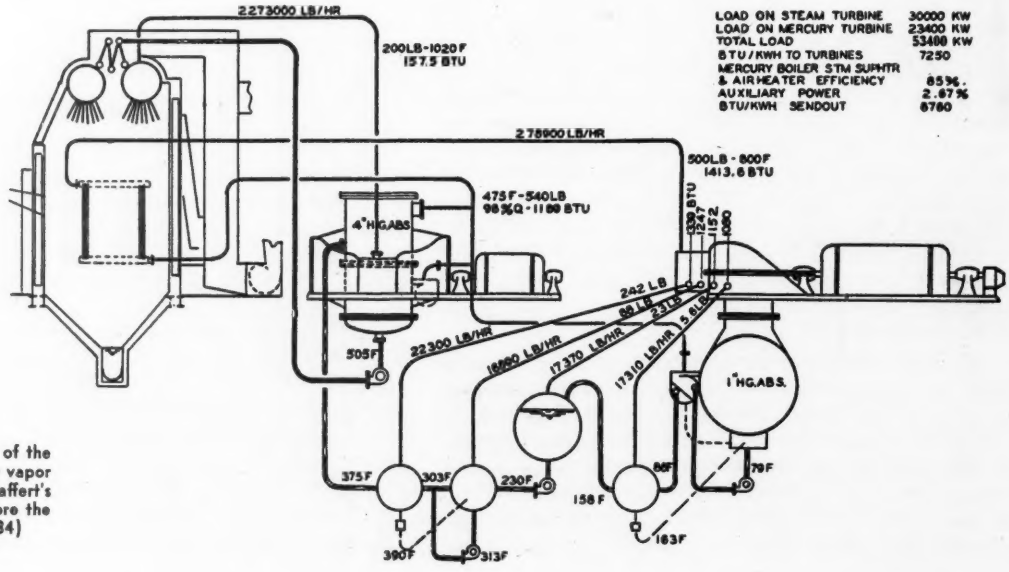


Fig. 1. The elements of the mercury-steam binary vapor cycle (from G. A. Gaffert's paper presented before the A.S.M.E. Dec., 1934)

cycle will always be higher than that of steam. While it is true that the efficiency of any thermal cycle increases as the temperature range is increased, it makes considerable difference whether the high initial temperature is obtained by increasing the pressure or by superheating the vapor. The energy required to superheat vapor to a certain temperature is only a fraction of that necessary to obtain the same temperature by increasing the pressure and maintaining the vapor in a saturated state.

Thus the gain in economy by superheating is small compared to the gain in economy by raising the temperature through an increase in pressure. Now with steam, even though we go to the critical pressure of 3226 lb. per sq. in., the saturated temperature is only 706 deg. F., while mercury at the same temperature has a gage pressure of only 5 lb. per sq. in. In the mercury cycle, the high temperatures are obtained by

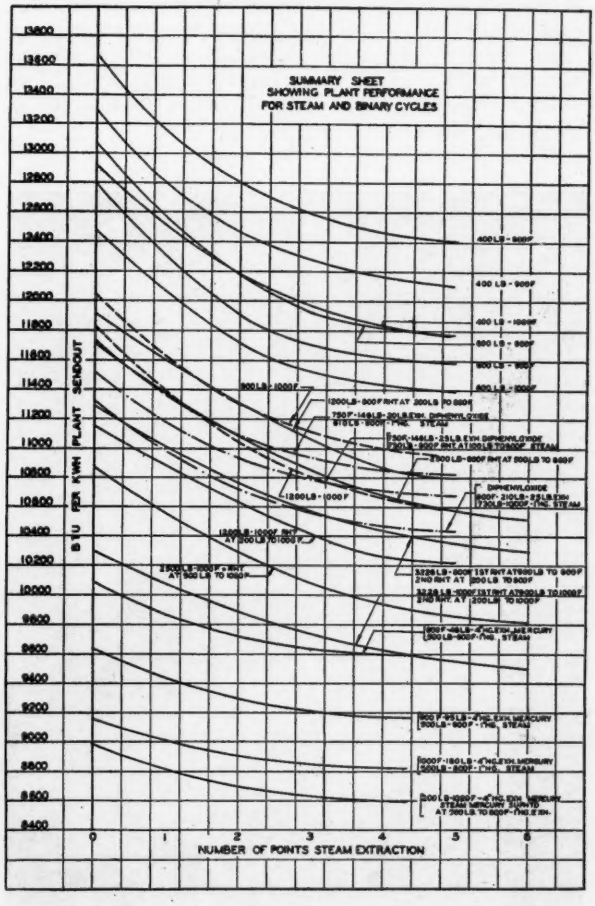

SUMMARY SHEET
SHOWING PLANT PERFORMANCE
FOR STEAM AND BINARY CYCLES
B T U PER KWH PLANT SENDOUT
NUMBER OF POINTS STEAM EXTRACTION

Fig. 2. Summary of plant performance for steam and binary cycles

increasing the mercury pressure and thus the mercury cycle more nearly approaches the ideal cycle efficiency.

Figure 2[1] shows how the heat rate of high pressure steam systems varies from 9500 to 12,000 B.t.u. per kw. hr., while the heat rate of mercury vapor systems varies from 8600 to 9600 B.t.u. per kw. hr. It will be noted that the 1200 lb. steam stations, even with reheat to 1000 deg. F., have a minimum heat rate of 10,200 B.t.u. per kw. hr., and that it is only the 3266 lb. steam system with two reheats to 1000 deg. F., which approaches the upper range of the mercury cycle. No

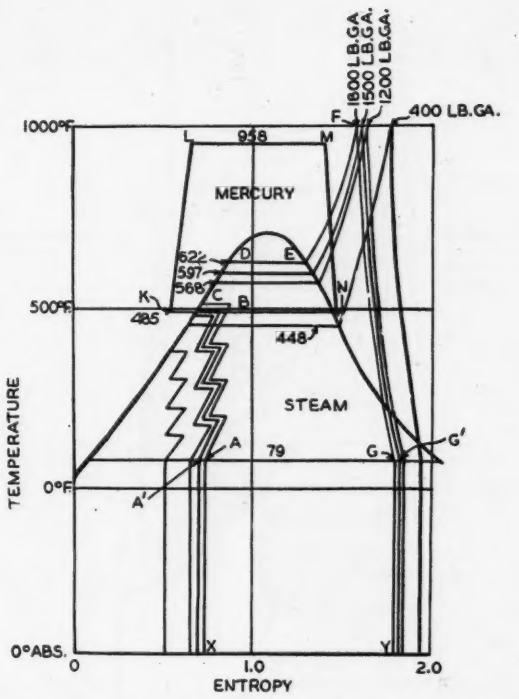


Fig. 3. Temperature-entropy diagrams for various steam and mercury cycles

By definition the change in entropy is the change in heat content in B.t.u. divided by the absolute temperature so that on a temperature entropy diagram (Fig. 2 above) areas represent heat in B.t.u. Thus for the 1800 lb. curve the area X A B C D E F G Y represents heat input and the area X A G Y the condenser loss of heat rejected. The useful area or work is then A B C D E F G A.

There is little difference in these areas for the 1800 and 1500 lb. cycle, but in the latter case the condenser loss, under the lines G1 A1, is considerably greater and consequently the efficiency is lower. It is obvious that the efficiency of the 400 lb. steam cycle is lower than the other three but with the mercury cycle added the net area is increased by K L M N without increasing the condenser loss so that the efficiency of the combined cycle is much higher. Theoretically, there is no reason why the steam cycle could not be superimposed on another fluid such as SO_2 and further increase the efficiency. This was experimented with extensively in Germany during the early part of this century but never reached commercial importance.

The temperature entropy diagram emphasizes the point discussed in the text, i. e., that the temperature of a superheated vapor cycle is by itself no measure of the cycle efficiency. The extraction cycle closely approaches the Carnot cycle and for saturated vapor the temperature limits give a close and simple approximation of the cycle efficiency. As the superheat is increased, this approximation becomes less valid due to the peak in the superheated region at the right hand side of the diagram.

such steam system has been considered thus far, and it probably would be quite as complex as the present mercury vapor systems.

The gain in ueful work of the mercury cycle over that of the high pressure, high superheat steam cycle, is clearly indicated on the temperature entropy diagram in Fig. 3. It shows that no matter how much the steam temperature is increased by superheating, an appreciable useful work area can always be added by superimposing the mercury cycle.

So much for the thermodynamic aspects of the mercury cycle. Its practical development in this country was brought about largely by the efforts of William Leroy Emmet of the General Electric Co. and Lucian Sheldon, also of G. E. In July 1923 an experimental mercury turbine installation of 1800 kw. was installed at Dutch Point Station of the Hartford Electric Co. The boiler used was a type which later became known as the "cheese box" boiler, since it consisted of a flattened

[1] From G. A. Gaffert's paper. A. S. M. E. Transactions, Vol. 56, No. 10, F. S. P. 56-11.

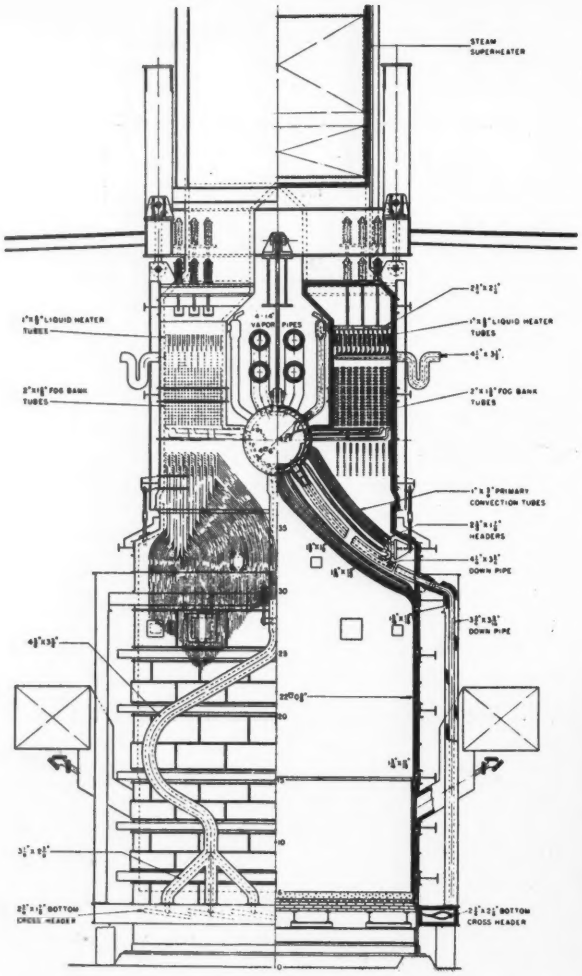


Fig. 4. Sectional elevation of the latest large size mercury-vapor boiler

cylinder, containing fire tubes. Fundamental difficulties were experienced with this type of boiler and in 1925 an entirely new type boiler was installed.

This new boiler was built for operation at 70 lb. pressure and was of what was called the unit tube type. Each tube was complete in itself, having both up passes for vapor release and down passes for liquid return. The boiler was constructed in sections, each section consisting of 60 tubes. This was the forerunner of the present porcupine boiler used in the mercury plants at Schenectady and Kearny.

Work with this installation proved so successful that in 1928 a new 10,000 kw. mercury turbine was installed at the South Meadow plant of the Hartford Electric Co. This unit operates with a throttle pressure of 85 lb. gage (880 deg. F.) and has shown an overall economy of 10,000 B.t.u. per kw. hr.

In 1933 the General Electric Co. constructed a 20,000 kw. mercury turbine plant at Schenectady with a throttle pressure of 125 lb. gage (950 deg. F.). The mercury boilers in this plant have water walls to obtain high furnace capacity and heat release and the steam turbine operated in connection with the mercury cycle is bled for industrial steam. A second 20,000 kw. mercury installation was made in 1933 at the Kearny Station of the Public Service Co. of New Jersey.

Both of these installations used porcupine type boilers, but more recently a new design has been developed which it is expected will eliminate certain difficulties experienced with the porcupine type. This new design has a single drum and no water walls in the furnace, the latter being cooled with liquid mercury tubes in the upper lengths of which vaporization occurs. This boiler is shown in Fig. 4.

This work at Hartford as well as Schenectady and Kearny has shown what may be accomplished with the mercury cycle with large installations. Perhaps the most interesting development in the use of the mercury cycle is the application of the mercury vapor cycle to comparatively small plants. During the past year two such installations have been made by the General Electric Co. in its own shops at Lynn and Pittsfield, Mass. Since these involve new, very special boiler designs, these units are described in the following article which is devoted to special type boilers. One of these units employs natural circulation, the other forced circulation. In each case, these installations have 1000 kw. mercury turbines and the exhausts supply 12,500 lb. of steam per hr. at 185 lb. gage, sufficient to generate an additional 900 kw.

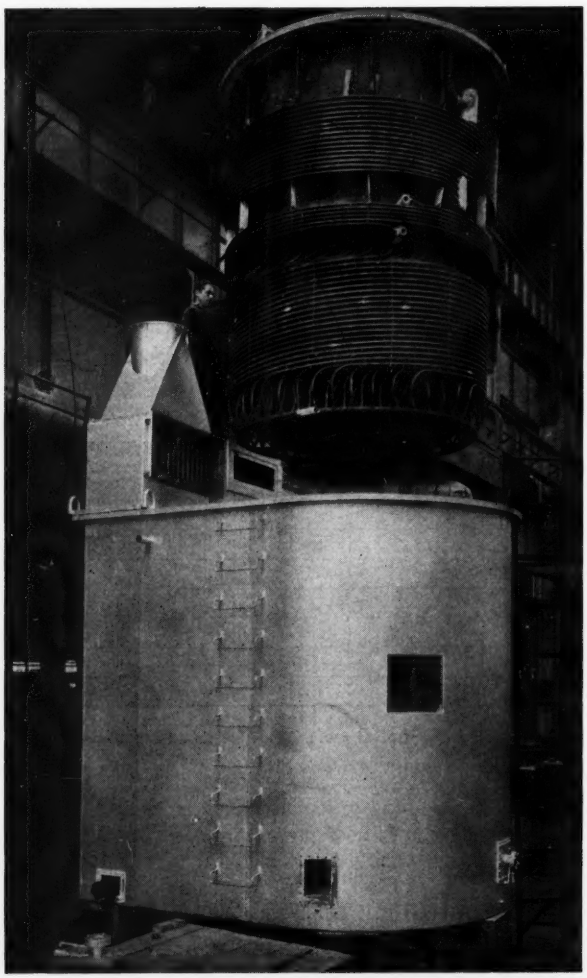


Fig. 5. Furnace, convection liquid heater and steam superheater tube assembly of the Lynn forced circulation boiler being lowered into the casing

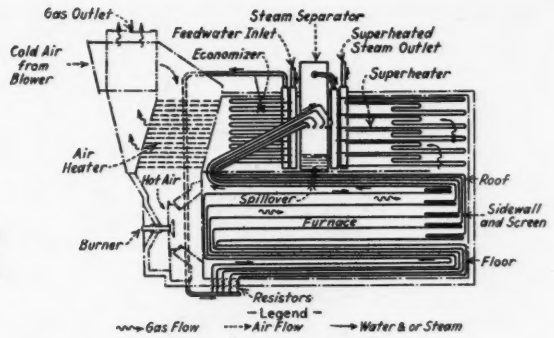


Fig. 1. Flow diagram of the experimental "Steamotive" boiler which is horizontally fired

Small, High Capacity, High Pressure Boilers

FOR MANY YEARS attempts have been made to produce small, compact, yet highly efficient steam power generating units which would be applicable to a variety of purposes and in many instances to mobile as well as stationary service. The old "Locomobile" was an early attempt in this direction and though it never attained much popularity in America, in Europe it was developed to a high degree of efficiency. It was essentially a coal fired tubular boiler with a tandem compound steam engine mounted on top of it. In Europe these units were built in various sizes from 50 to 2000 hp.

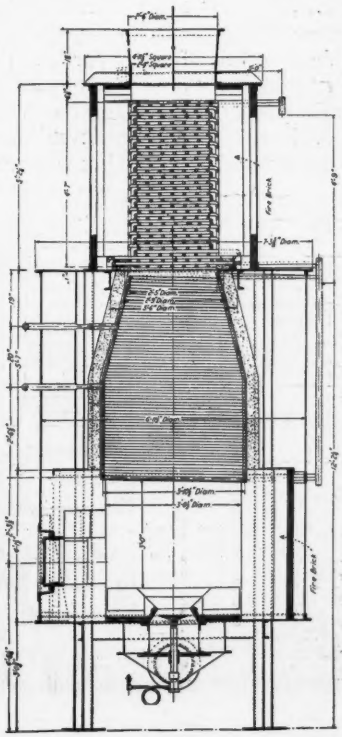


Fig. 2. A sectional view of the high pressure boiler at Purdue

Other more scientific developments of this kind formed the basis of the early steam automobiles. The White automobile boiler, for example, was a high compact gasoline or kerosene fired boiler of the semi-flash type into which water was pumped at one end as fast as the steam was taken out at the other.

In recent years the Doble high pressure boiler carried the idea to a point of considerable success in units operating at 1500 lb. per sq. in. and with steam temperatures of around 800 deg. F. This boiler was the forerunner of the present day Besler Boiler which is a continuous flow, force feed, non-water level, counterflow type boiler having no drums, headers or storage tanks. At the present time Besler Systems offer three standard sizes of units, ranging in capacity from an output of approximately 1500 lb. of steam per hr. at a working pressure of 1250 to 1850 lb. per sq. in. and any desired temperature from a few degrees superheat up to a total of 1000 deg. F.

This boiler can be conceived as a long pipe, heated over its entire length, with water pumped into one end and steam emerging from the other end. In actual arrangement this pipe is of course built in the form of a coil, and since the flow is forced, the disposition of coils can be suited to zones of temperature without regard to gravitational or other effects. On the larger type units, parallel coils are used but the principle remains the same. The boiler has three parts or zones. The top, being farthest from the fire can be referred to as the economizer. The water enters this section through a series of pancake coils which grow gradually in diameter as the circuit approaches the fire which allows for the increased volume as steam is generated in the tubing.

From this economizer zone the steam and water pass to the second or firebox zone, also called the firebox helical coil. This helical coil is tightly wound and forms a complete saturated steam wall for the combustion space. The heat released within this space is above one-half

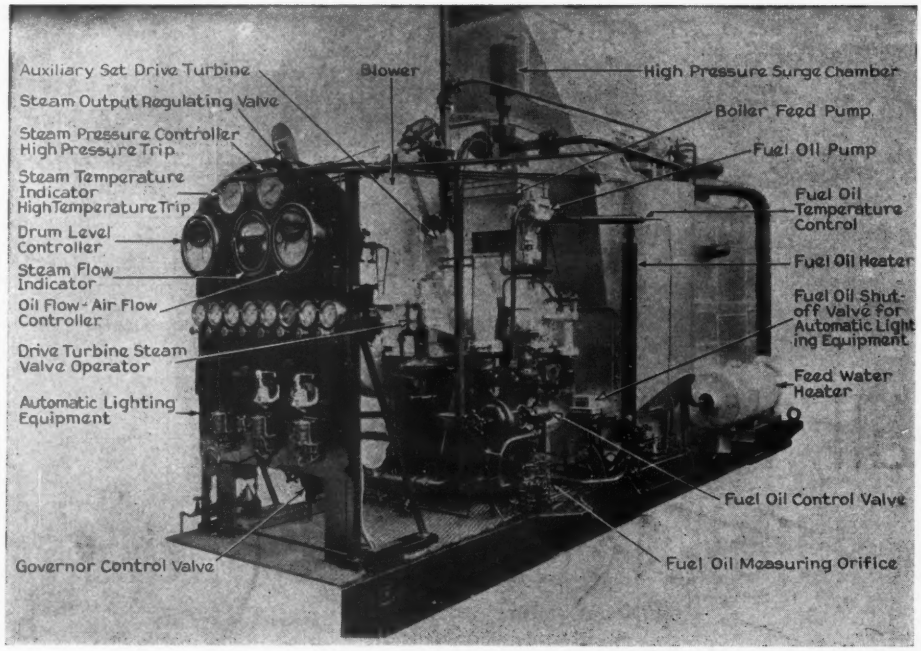

Auxiliary Sat Drive Turbine
Steam Output Regulating Valve
Steam Pressure Controller High Pressure Trip
Steam Temperature Indicator High Temperature Trip
Drum Level Controller
Steam Flow Indicator
Oil Flow - Air Flow Controller
Drive Turbine Steam Valve Operator
Automatic Lighting Equipment
Governor Control Valve
Blower
High Pressure Surge Chamber
Boiler Feed Pump
Fuel Oil Pump
Fuel Oil Temperature Control
Fuel Oil Heater
Fuel Oil Shut-off Valve for Automatic Lighting Equipment
Feed Water Heater
Fuel Oil Control Valve
Fuel Oil Measuring Orifice

Fig. 3. General arrangement of equipment on the experimental Steamotive unit as installed at Lynn. All auxiliaries are driven by a single turbine

million B.t.u. per cu. ft. per hr. From the boiler entrance through this helical zone two circuits are employed in parallel which merge at the helical outlet to form a single circuit in the third zone.

The third, or superheat zone, is located between the combustion space and the economizer, which it is claimed is the proper location to achieve complete counterflow. This superheat section is cleanable throughout and is formed of circumferential helical tubes joined by straight cross tubes. The boiler tubing is strong enough to allow operation at critical pressure if desired. The Besler boiler at the present time is receiving application in the railway field for driving a streamline steam train on the N. Y., N. H. & H. R. R.

The special boiler installed at Purdue several years ago is another boiler of the series or once-through drumless type in which forced circulation and partial counterflow is used. The feedwater enters at the top and descends through a series of horizontal zigzag coils in the upper section. It is then conducted to the bottom of the furnace wall, in the coils of which it rises and flashes into steam which becomes superheated before the outlet at the top of this coil is reached. The unit was built for operation at pressures from 1500 to 3200 lb. pressure and can deliver about 6000 lb. of steam per hr.

The most recent development of this kind is that involved in the "Steamotive" unit developed jointly by the General Electric Co., The Babcock & Wilcox Co. and the Bailey Meter Co. This is a complete small steam-electric generating unit, automatic in operation and compact enough to adapt it for either stationary or mobile use.

A flow diagram of the boiler used in the "Steamotive" is shown in Fig. 1. From the burner the flame and gases pass horizontally through the completely water cooled furnace, thence up and back with a 180 deg. turn into the superheater, flowing around the separator, through the economizer and air heater and up the stack. The air for combustion leaves the blower at relatively high pressure, passing through lanes intersecting the stack and down around the air heater tubes to the oil burner. There is no induced draft fan, the blower forcing the air through the burner and furnace under pressure.

Feedwater enters the economizer inlet header, and, after leaving the outlet header, is divided into five circuits, all five of which form the floor, sides, and roof of the furnace as well as the two sets of loops forming the boiler screen. All steam is generated in these five furnace and boiler circuits and enters the separator with a surplus of about 400 lb. of water per hr. in each circuit. From the separator the dry steam goes through the superheater directly to the main turbine. The water from the separator is called the "spillover" and it passes through a heat exchanger to the hot well where it mixes

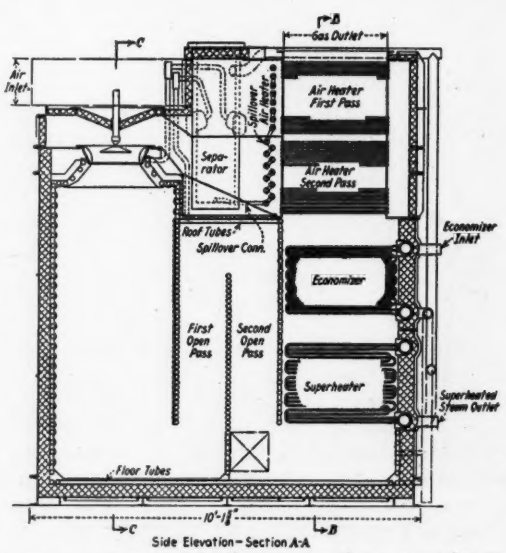


Fig. 4. A vertically fired open pass Steamotive boiler

with the condensate and is re-fed to the boiler by the feed pump.

The desired rate of water flow is established by measured indications of total boiler steam flow and separator-drum level, and the variable water-flow governor regulates the speed of the turbine driving the auxiliary set to maintain this water flow regardless of variations in steam or water pressure, feed pump efficiency or other variables.

The burner is provided with a propane torch with dual spark ignition and with a photoelectric flame indicator.

In the experimental "Steamotive" unit at the Lynn plant of the General Electric Co. the unit ran 40 con-

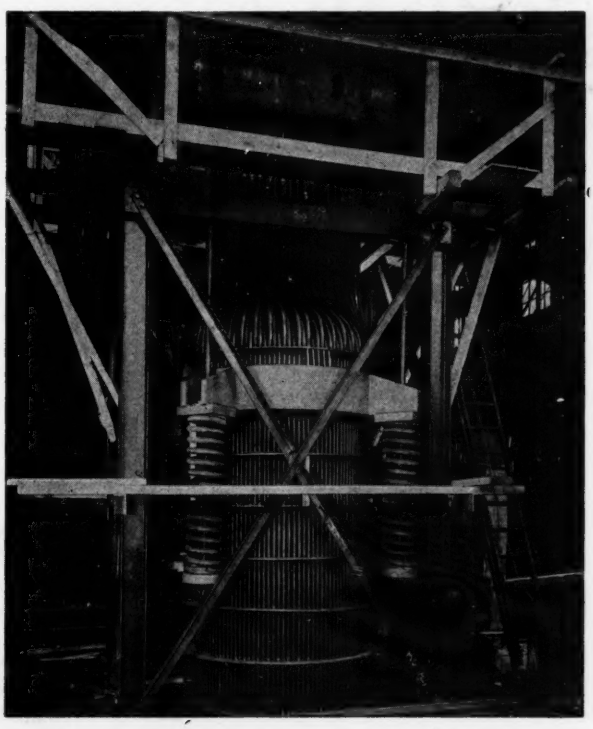


Fig. 5. Tube assembly for the oil fired natural circulation mercury-vapor boiler at the G.E. Pittsfield Works

tinuous hours at 21,000 lb. per hr. At the normal rate of 16,000 lb. of steam per hr., the feedwater pressure entering the economizer is 1610 lb. and the steam pressure at the superheater outlet 1390 lb. The steam temperature at an output of 16,000 lb. per hr. is 870 deg. F. which rises to 910 deg. at 22,000 lb. per hr. Combustion rates vary from 25,000 to 375,000 B.t.u. per cu. ft. of furnace volume per hr. and the boiler efficiency from 75 per cent at 22,000 lb. per hr. to 85.5 per cent at 5000 lb. per hr.

Another extremely interesting development in special types of small boilers is the mercury-vapor units developed by the General Electric Co. for use in its own shops. This development which was referred to briefly in the preceding article, in each of the two units developed, consists of a mercury boiler, a mercury turbine, a condenser-boiler and a steam turbine. These small units embody important modifications in design resulting from experiences gained in the large mercury vapor installations at Hartford, Kearny and Schnectady. The mer-

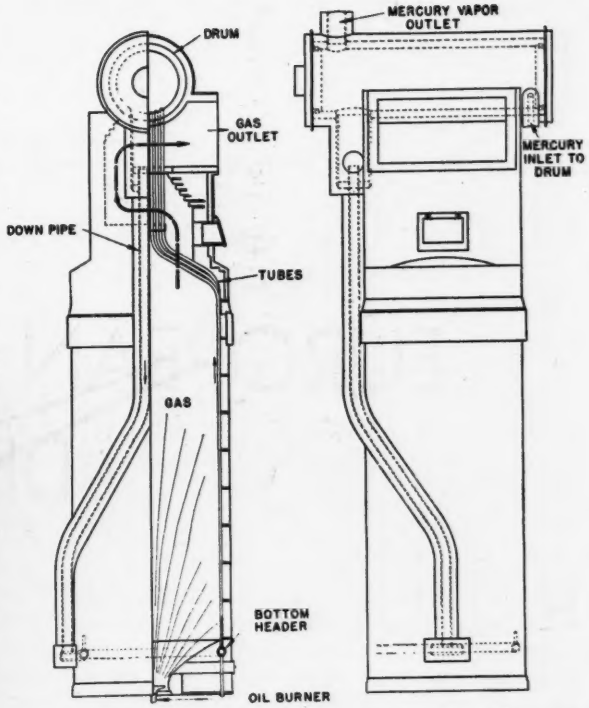


Fig. 6. Semi-section and elevation of the 1900 kw. natural circulation Pittsfield unit shown in Fig. 5

cury turbines are rated at 1000 kw. and the condenser boiler supplies 12,500 lb. per hr. of 185 lb. ga. steam, sufficient to generate an additional 900 kw. of electrical energy.

The boiler installed at Pittsfield, shown in Fig. 6, is of the natural circulation type with tubes similar to the liquid mercury cooling walls in the boilers at Kearny and Schenectady. The unit installed at Lynn, Fig. 7 and Fig. 5, on page 76, see preceding article, is of the forced circulation type with all the heating tubes filled with liquid mercury and all the vapor formed in a separate chamber remote from the combustion space.

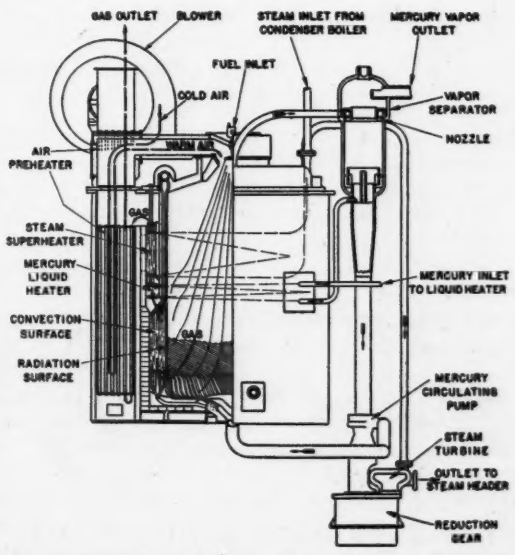


Fig. 7. Semi-section of the 1900 kw. Lynn forced circulation boiler

European Boiler Development, especially in high pressure technique has followed along lines which are quite different from that in America. A number of very interesting schemes for generating steam have been devised some of which have been brought to a high state of commercial development. These are described in this article.

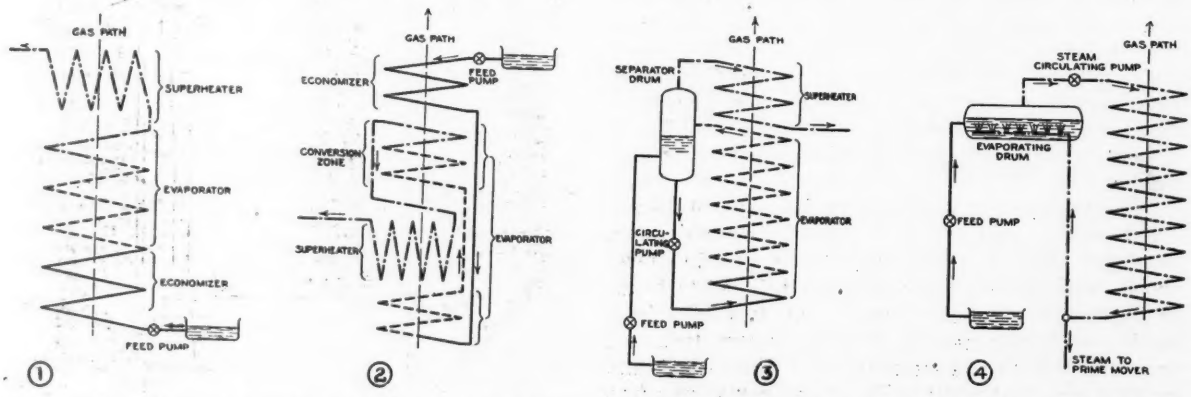
EUROPEAN BOILER DEVELOPMENTS

HIGH PRESSURE BOILER DEVELOPMENT in Europe as pointed out in the article on unorthodox boilers on page 72 has proceeded along lines which are quite different from those which have characterized American practice. This is due to a variety of conditions; to a difference in temperament, to different educational methods in European colleges and universities, to less abundant fuel resources and, as far as the general design of plants and sizes of plants is concerned, to considerations involving national defense. The degree to which national defense considerations sometimes influence the design of engineering projects in Europe is not generally appreciated by engineers on this side of the Atlantic. In Germany, for example, in contrast with American practice, relatively few new boiler units of large capacity are being installed, the idea being not to place too many eggs in one basket as regards vulnerability from attack. Indeed, it is understood that in Germany all new power plant plans are subject to governmental approval from the standpoint of national security. One large German company recently made substantial additions to its power generating facilities but instead of increasing the capacity of its central plant as would appear most expedient and economical from an investment and operating standpoint, the new capacity was installed in two new and widely separated plants, interconnected by both steam and electric lines. Again, in a recent issue of the Brown Boveri Review, there was shown a layout for a 20,000 kw. Velox boiler and turbine plant installed in a bomb-proof excavation in rock. This factor of national defense is cited merely as an example of the fundamental difference between Europe and America in thought and practice. This particular factor, however, is probably the least important in influencing the trend of development toward such special boilers as the Velox, Loeffler, Benson and other unusual types to be considered here.

The general principles of these boilers have been presented in another article. Here, however, we will describe the features of these boilers in greater detail, and insofar as possible, give the reasons leading to their development.

In general, these special types of boilers can be grouped into either of two classes, first the forced circulation types in which steam or water is circulated continuously through the heating elements as in the Loeffler, La Mont and Velox boilers, and, secondly, the so-called "once through" type of which the Benson boiler is a typical example.

A diagram of an early type of "once through"



Figs. 1-4. Diagrams of various new types of boilers. 1. An early type of once through boiler. 2. Later type of once through boiler in which the conversion zone is located in a region of lower temperature. 3. Forced circulation boiler with circulation pump, typical of the LaMont and Velox boilers. 4. Forced circulation boiler with a steam circulating pump as used in the Loeffler boiler

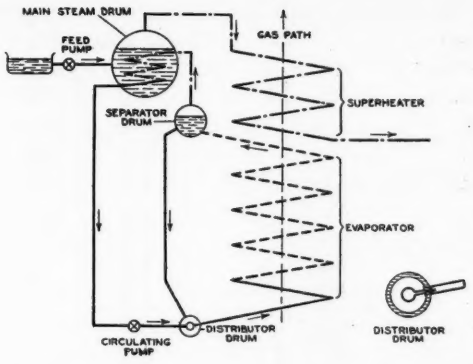


Fig. 5. Assisted circulation boiler with indirect steam generation

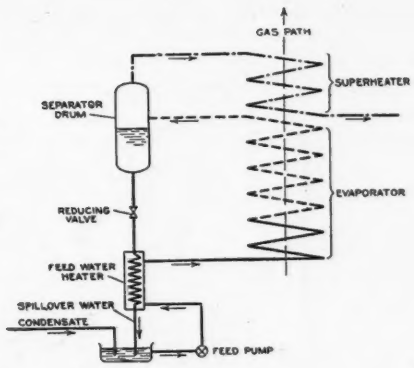


Fig. 6. Diagram of a spillover type boiler

boiler is shown in Fig. 1. This has a feed pump which delivers water into one end of a long tube from the opposite end of which steam is delivered. Multiple parallel circuits may be used instead of a single tube. Generally, boilers of this type have small diameter tubing coiled into helical form. A once-through boiler of later design is represented by the diagram in Fig. 2. In this boiler, the conversion zone, i.e., the section where the conversion of water into steam occurs, has been located in a a region of lower gas temperature.

The forced circulation type of boiler having a circulating pump is shown in Fig. 3. This principle is used in the La Mont, the Velox and the Loeffler boilers with one point of difference in the Loeffler. In the Loeffler boiler, the circulating medium is steam instead of water. This is shown in Fig. 4 In both the Velox and the La Mont boilers a much larger quantity of water is circulated than is converted into steam, the former circulating approximately twice and the La Mont eight times the amount of steam although these ratios can be varied within wide limits. The amount of power required by the circulating pumps must, of course, be included in the power requirements for operation, but this is not large as the suction of the pump carries boiler pressure and the pump has to operate against only 30 to 40 lb. head. In the Loeffler boiler, however, the delivery pressure is 50 to 60 lb. above the working pressure of the boiler and a greater weight of steam is circulated than is delivered to the prime mover.

In some of the European types, the steam is generated indirectly as shown in Fig. 5. In this system which is exemplified by the Schmidt-Hartmann boiler, the evaporation of the working steam takes place in an evaporator drum heated by coils supplied from a primary steam circuit operating at a higher pressure than that of the working steam.

While we are discussing these different types of boilers, one other scheme should be mentioned, although this particular scheme was developed by American manufacturers. This is the spill-over type illustrated in Fig. 6. The feed pump forces water through tube coils from which a steam and water mixture is delivered to a separator drum. The steam passes from the drum through the superheater to the point of use and the water spill-over escapes through a pressure reducing resistance and feedwater heater to the suction of the feed pump.

So much for the general circulation principles of these boilers. We will now consider some of the more important makes in grreater detail, starting with the Benson boiler.

The Benson Boiler

The generation of steam at high pressures and temperatures involves two difficulties: one the formation of steam bubbles on the tube walls with insulating effect; the second, that priming results at high pressures when the amount of steam disengaged per unit area of the water exceeds a certain critical quantity. To overcome these difficulties Mark Benson suggested the evaporation of the water under critical conditions of temperature and pressure. At the critical pressure, 3226 lb. per sq. in. the temperature of the water is 705.2 deg. F. and at that pressure water changes into steam without the addition of heat of evaporation. Water is simply heated up to the critical temperature and turned into steam with the slightest decrease of pressure.

In the Benson boiler, water is forced at a greater pressure than 3226 lb. per sq. in. through a heated coil, being gradually heated to a temperature of 705.2 deg.

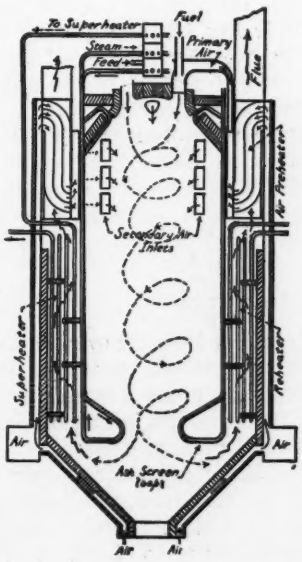


Fig. 7. An early form of Benson boiler

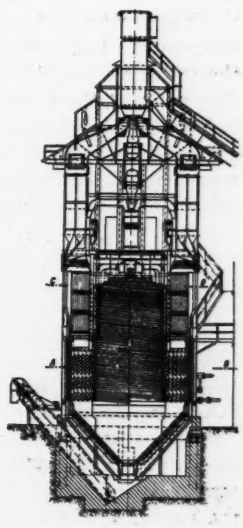


Fig. 8. A later type of Benson Critical Pressure boiler

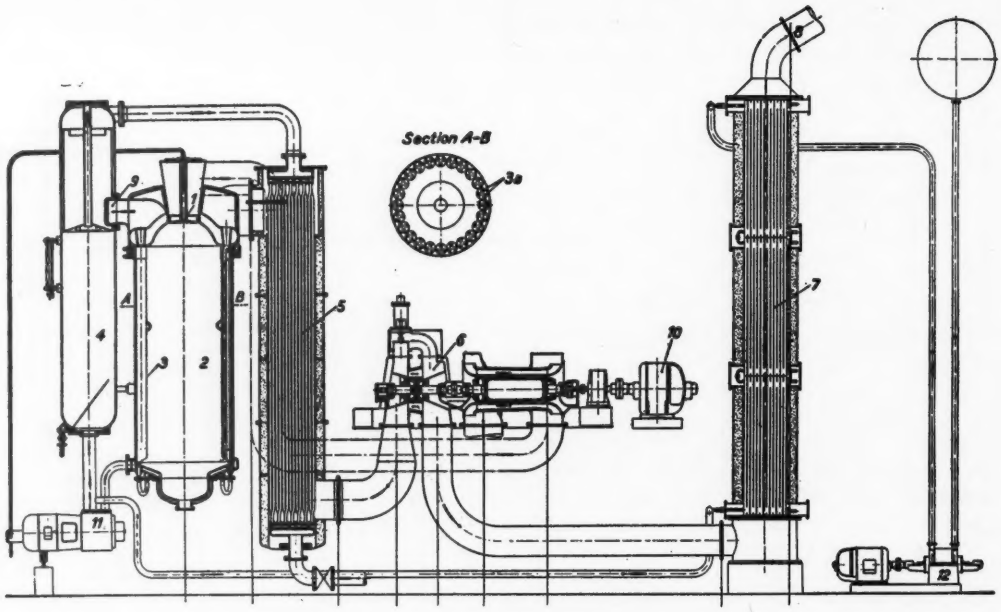


Fig. 9. Schematic diagram of the Velox Steam generator

When it attains that temperature, the water turns into steam with no further additions of heat, after which it is superheated by the further addition of heat.

An early arrangement of the Benson boiler is shown in Fig. 1. The tubes are looped in such a way that each tube forms a part of the furnace wall, ash screen, and roof, these elements being thus connected in series. Burners for pulverized coal, gas, or oil are located in the top of the furnace, and the secondary air enters through adjustable side openings. The furnace gases pass downward through the furnace and then ascend through annular passages containing the superheaters, reheaters, and air preheaters, and thence to the stack. As the specific volumes of the saturated liquid and vapor are equal at 3226 lb., no steam drums for steam separators are necessary.

In later Benson units, the tubes in the furnace are arranged helically as shown in Fig. 8. This distributes the heat more uniformly among them. The coils are arranged in two sections of which the upper one heats the water to the critical temperature and the lower one does part of the superheating. The first experimental Benson generator was operated at Rugby but later the control for certain countries was acquired by the Siemens-Schuckert Co. of Berlin, who have carried out a large amount of development work.

The Velox Boiler

The Velox boiler developed by Brown Boveri & Co. is of the forced circulation type, but is unusual in its design in that it uses combustion under a pressure of about 15 to 30 lb. per sq. in. and operates in conjunction with a gas turbine for driving the air compressor.

A diagram of the Velox steam generator is shown in Fig. 9. Combustion of the fuel takes place in the combustion chamber 2 were air and fuel enter through the burner 1; the air at a pressure of 35 lb. per sq. in. abs. and the fuel at about 300 lb. gage. The gases give up part of their heat content by radiation to the external walls of the evaporator tubes 3 which line the wall of the combustion chamber. More heat is transmitted by convection while the gases pass upward through the internal tubes 3a of the evaporators to the exhaust flue gas collecting chamber. Thus the initial temperature of combustion is reduced to about 1500 deg. F. while the pressure drops to about 33 lb. abs. With this temperature and under this pressure the gases enter the superheater 5, to leave it, cooled to

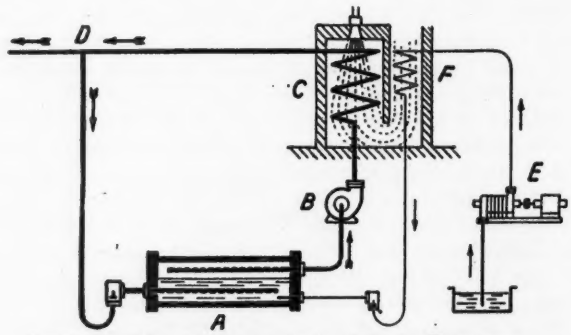


Fig. 10. Schematic representation of the Loeffler system

about 900 deg. F. at a pressure of about 31 lb. The gas turbine 6, which is then entered, causes the flue gas temperature to drop to about 700 deg. F. while the pressure drops to 16 lb. abs. The corresponding heat drop, apart from small radiation and bearing losses, is entirely converted into mechanical energy and transmitted to the blower where it is reconverted into heat with a corresponding rise in the air temperature. Finally, the gases escape through the feedwater heater 7 which forms part of the chimney. The gases are discharged to the atmosphere cooled to about 200 deg. F.

The water and steam circuit is as follows: The makeup water is fed by the feed pump 12 through the preheater 7 to the separator 4, where it mixes with the

evaporating water. This water is kept in continuous circulation by the circulating pump 11 which pumps through the combustion chamber 2 and evaporating tubes 3 back to the separator 4 at the rate of about ten times the full load evaporation.

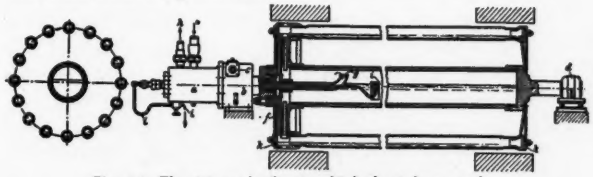


Fig. 11. The Atmos boiler in which the tubes revolve

The circulating pump gives the circulating water a sufficient pressure head to impart a high velocity to the steam and water mixture which is forced through nozzles into vertical drum and the steam and water are thus separated by centrifugal action. The separating capacity of this centrifugal separator is about 100 to 200 times greater than that of the normal drum. The water then falls through a small gap in the lower partition of the separator, while the steam enters the superheater 5, where it is superheated to the desired amount for use in the steam turbine.

Aside from the scheme itself, the Velox boiler has many interesting constructional features which make it a highly efficient, compact device adaptable to a wide variety of applications. In many acceptance tests the efficiency obtained has been over 90 per cent. It has quick starting characteristics and is under completely automatic control. Full steam pressure can be attained from 4½ to 8 min. Many of these units are in successful operation in Europe.

The Loeffler Boiler

In the Loeffler forced-circulation boiler developed by the Witkowitzer Bergban and Eisenhutten G. of Czechoslovakia, the principal used is that of passing very highly superheated steam into water. In this scheme the water is evaporated solely by means of superheated steam—the furnace heat being applied only to the economizer—and a steam pump is used to circulate the vapor through the system. The details are shown in Fig. 10. Saturated steam formed in the vaporizing drum A is forced by means of the steam pump B through the superheater C. About 2/3 of the issuing high temperature steam is sent back to the vaporizer, only the remaining third being delivered to the steam main. The steam pump, which is needed to overcome the resistance to flow through the apparatus, absorbs energy in amounts dependent, among other things, on the specific volume of the steam handled which of course is a function of the pressure. Should the working pressure be of the order of, say, 250 lb. per sq. in., the pump would require more energy than the boiler could furnish, but at pressures of around 1850 lb. per sq. in. it is claimed the pump requires only 2 per cent of the boiler output. Thus, the Loeffler system is inherently a high pressure system and is not used for pressures below 1500 lb. per sq. in.

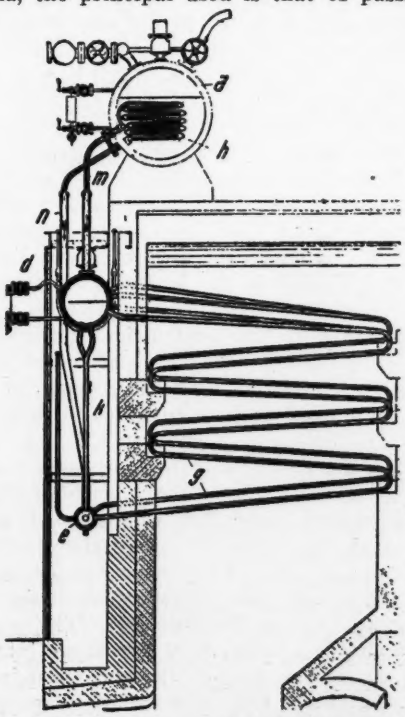


Fig. 12. Schematic diagram of the Schmidt-Hartmann boiler

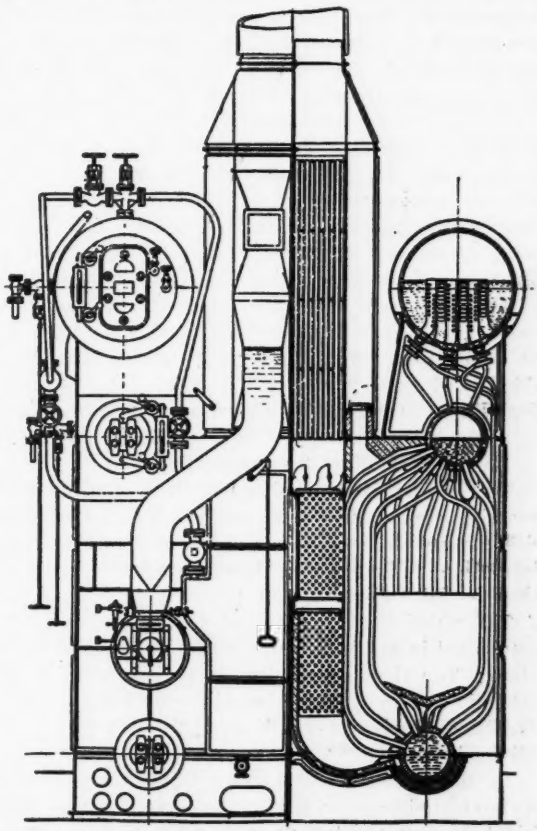


Fig. 13. Vertical elevation of a 738 lb. Schmidt-Hartmann boiler designed for marine service

Many of these units have been installed in Europe with exeellent results and with steam temperatures over 900 deg. F. Two large units have been installed in the Brimsdown power station in England, each having a rated evaporation of 210,000 lb. per hr. when running at 2000 lb. per sq. in. and with 940 deg. F. superheated steam temperature.

The La Mont Boiler

The La Mont boiler is a single tube forced circulation boiler, invented in the United States but now being

developed in England. In basic principle, the design consists of one steam and water drum of relatively small size situated outside the furnace setting, and a large number of 1 in. dia. solid drawn steel tubes of great length, arranged in sets. The water is supplied to the boiler drum by a separate feed pump and then passes to a high-pressure centrifugal circulating pump, which discharges it to the headers. There are two headers from which the water passes by inlet nozzles and strainers to each set of tubes. One header is vertical and supplies the sets of tubes which extend, one above the other, horizontally around the entire combustion space, covering the front, back, and two side walls, and return to the drum. The other header is horizontal and supplies sets of transverse tubes across the top of the combustion chamber. They are also led back to the drum. This constitutes the convection section evaporator while the tubes forming the combustion chamber walls form the radiant section evaporator. All steam is generated in the tubes, but the main water circulation is considerably in excess of that required for the steam formed. The forced-circulation centrifugal pump, which is directly driven by a motor or steam turbine, operates under conditions of 35 lb. per sq. in. pressure difference between the drum and the tubes. There is a superheater over the combustion chamber, and above this the economizer, while if desired an air heater may be added. All these parts are formed of 1 in. tubes. La Mont boilers are suitable for pressures up to 2000 lb. per sq. in.

The Atmos Boiler

The original Atmos boiler consisted of a number of revolving steam generating elements (rotors) together with a superheater and economizer using forced water circulation. The rotors 1 ft. in diameter were set in a furnace and rotated by an electric motor at a speed of 320 r.p.m. Because of the rotations the water is distributed in a thin layer over the inner surface of the rotors. The thickness of this layer is controlled automatically by the feedwater regulator and in the original installation varied from 2.5 in. at no load to 1.5 in. at full load.

In the original rotor design the frame disposition to counterbalance the stuffing box reaction was insufficient for multi-rotor designs, so a new design was developed, with unilateral and balanced stuffing boxes. The water inlet and steam outlet are located at the same end of the tube to cancel the reaction caused by the axial thrust. This was later simplified by using a single unilateral stuffing box.

Another type called a squirrel cage rotor was also developed. This, as shown in Fig. 11 consists of a tube of large diameter surrounded by a crown of smaller tubes. Substitution of this type of rotor for the 2 single tube rotors in the first boiler resulted in an increase of output from 5280 lb. to 5000 lb.

Not much has been heard about the Atmos boiler lately although it is understood that active investigations are proceeding and minor improvements are still being made.

The Schmidt-Hartmann Boiler

The Schmidt-Hartmann boiler, as pointed out in the introductory parapraphs of this article is based upon the indirect method of evaporation. The heating and evaporation of the water is done entirely by high pressure steam generated from distilled water in a coil boiler with very small outside drums. The outlet from this system leads to a coil heater in the boiler drum where the heat transfer takes place and where the heating steam in condensed into water.

A schematic diagram of the Schmidt-Hartmann boiler is shown in Fig. 12. The heating water, which serves as a heat conductor, circulates in the tube coils "g" is evaporated in these coils and freed from any accompanying moisture in the separator drum d. Then it passes up through pipe, on to a heat exchanger h, which is in the boiler drum, a, condenses there, giving up its latent heat, and finally, flows back to the bottom header e, by gravity through the pipe n. The water separated in the separator drums likewise descends to the bottom header through the downcomer pipe k so that in the evaporation coil there is not only a simple evaporation, but an active water circulation, through which intensive cooling of the heating surface in the furnace is obtained. The feedwater for the boiler is pre-heated and introduced into the boiler drum a, where it evaporates.

The Ramsin Boiler

The Ramsin forced-circulation boiler developed in Russia is of the "once through" type. One Ramsin boiler has been in commercial service at Moscow since December, 1933. This unit is a small tube boiler rated at 440,000 lb. per hr. with steam pressure at 2100 lb. per sq. in. and 900 to 923 deg. F. total temperature. The boiler is designed for pulverized coal but is being fired with oil.

The radiant heating surface of this unit consists of four sets of tube banks, surrounding the furnace and connected so as to secure a balanced effect. The connection heating surface consists of the superheater, economizer, reheater and air heater. A floor screen is also provided. The condensate after passing through a deaerating heater is forced by the feed pump through bleeder heaters to 24 hanger tubes supporting the radiant heating surface in the furnace. From here it passes to the economizer sections and then to the upper radiant sections, thence to the lower sections where some superheating takes place and finally to the convection superheater. Unlike the Benson boiler design, the transition from water to steam occurs in the radiant section.

During the year 1935, the average gross operating efficiency was 84.1 per cent with loads varying between 132,000 and 176,000 lb. per hr.

This present year, the power program for Soviet Russia provided for the construction of some 1,300,000 kw. of new capacity, the greater part of which is supplied by large boilers of the Ramsin type. In fact, the Central Boiler and Turbine Institute has developed its plans around the use of this boiler.

The boilers described in the foregoing parapraphs are the principle European developments in the boiler field. There are others however, some of which are modifications or combinations of the above schemes, but which have not attained the same commercial success. Most of these super-pressure generators, it will be noted use the forced circulation principle. The relative advantages and disadvantages of forced and natural circulation is a complicated subject on which much difference of opinion exists, but for very high pressures, its advantages probably outweigh its disadvantages.

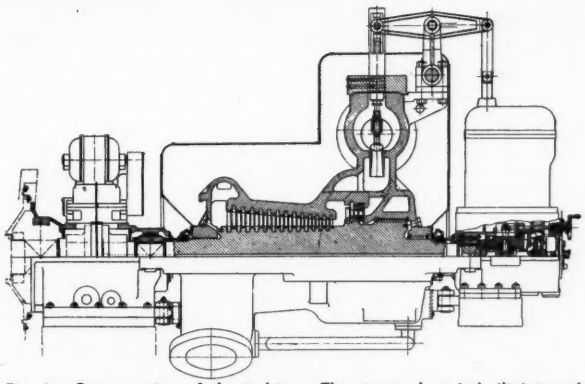


Fig. 1. Cross section of the turbine. The steam chest is built integral with the cylinder cover. Note the openings at the ends of the last two rows of stationary blades provided for draining moisture from the steam direct to the condenser

25,000-kw. turbine, largest of the new single cylinder 3600 r.p.m. type yet built operates at 640 lb. ga., 825 deg. F. Occupies 10.9 sq. ft. of floor space per 1000 kw., weighs 7.3 lb. per kw. and is supplied with steam by two 130,000 lb. per hr. pulverized coal fired, bent tube boilers.

MONTVILLE Sets a New Record

HIGH SPEEDS have gone hand in hand with high temperatures to make the present building program one of, if not the most, significant in the history of power development. As the maximum speed available for use with a direct connected 60 cycle generators, 3600 r.p.m. turbines were used to a certain extent previous to the depression. These were of small size, however, and the course of development was interrupted for several years.

Turbine manufacturers put these years to good use, however, and emerged from the depression with a complete line of 3600 r.p.m. machines[1]. Of these, the first important one ready for operation is the 25,000 kw., 3600 r.p.m. Westinghouse single cylinder unit in The Connecticut Light & Power Co.'s Montville Station at Uncasville, Conn.

[1]See Present Status of Steam Turbines by E. R. Kauffman, Power Plant Engineering, March, 1937, page 153.

Space and Weight

This unit sets a new record for single cylinder 3600 r.p.m. turbines and the importance of the development is indicated by the fact that the unit weighs only 7.3 lb. per kw. of capacity and occupies but 10.9 sq. ft. of floor space per 1000 kw. A comparable 1800 r.p.m. unit of the same size weighs 16.6 lb. per sq. ft. and occupies 21.5 sq. ft. per 1000 kw., an increase of well over 100 per cent for both items. Previous to the Montville installation the largest 3600 r.p.m. unit of this type was rated at 10,000 kw., weighed 8.5 lb. per kw. and occupied 13.3 sq. ft. per 1000 kw.

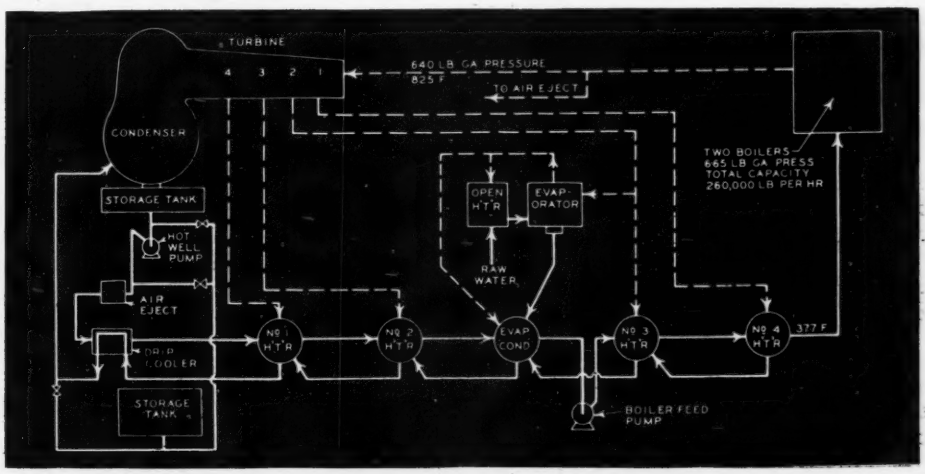


Fig. 2. Flow diagram of the station. The turbine heat rate is below 10,000 B.t.u. per kw. Heater drains are cascaded and pass through a drip cooler to the condensers

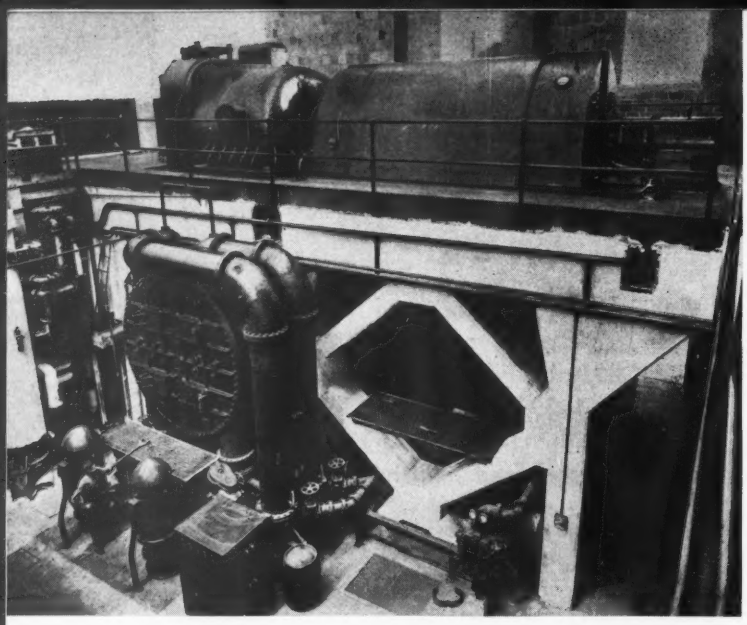


Fig. 4. Photograph taken as the generating unit construction was nearing completion. Note the vertical circulating pumps and heaters.

The turbine is rated at normal conditions of 640 lb. ga., 825 deg. F., 29 in. of vacuum but maximum contract conditions are 675 lb. ga., 850 deg. F., 29.3 in. of vacuum. Steam will be supplied by two Combustion Engineering three drum bent tube 130,000 lb. per hr. boilers operating at a drum pressure of 725 lb. and arranged as shown by Fig. 3. Each unit has 9140 sq. ft. of boiler heating surface, plus 2699 sq. ft. of water wall and slag screen surface, a 4000 sq. ft. Elesco superheater, and a 19,400 sq. ft. of Ljungstrom air heater surface. Superheat is controlled thermostatically at 850 deg. F. by bypass dampers. The furnace volume is 6200 sq. ft. The boilers also have automatic combustion control and cyclone dust collectors.

Furnaces are fired, horizontally, by pulverized coal, two unit mills being provided for each boiler. Fans are motor driven, one forced and one induced per boiler. Forced draft fans rated at 40,000 c.f.m. have vane control, induced draft fans, rated at 70,000 c.f.m. are driven through hydraulic couplings. The 20,000 sq. ft. condenser is supplied with water by two vertical circulating pumps visible in Fig. 4.

The feedwater heating cycle utilizing four stages of extraction is shown by Fig. 2. Vapor from an evaporator, using steam from the second bleed point, is condensed in an evaporator condenser following the second heater. Boiler feed pumps take their suction from the evaporator condenser and pump through the remaining two heaters to the boiler. All heaters, including the evaporator condenser are cascaded and the combined drains from the last heater pass through a drip cooler to the main condenser.

A number of interesting features are incorporated in the turbine design. The throttle valve is of the new inverted type opened by oil pressure under control of a small hand wheel and may be tripped by the overspeed governor or from the switchboard by the action of a solenoid trip. The valve is of carbon molybdenum with stainless steel trim. The steam chest is integral with the cylinder cover, with steam controlled by seven unbalanced plug type valves, so mounted on a bar that they open in sequence under actuating forces from the relay type governor.

Nozzles are divided into seven groups each supplied by a single valve in the steam chest. Bypassing of the high pressure blading for carrying overloads is not employed in this unit but the general turbine design is such as to allow the incorporation of this feature in subsequent machines. The nozzle blocks consist of stainless steel vanes welded into steel rings and the impulse wheel is of the conventional two row type. The forged spindle of chrome-nickel molybdenum steel has a disk shrunk on the shaft for carrying the last row of blades. Blades in this last row are 20 in. long, with a tip diameter of 80 in. and a tip speed of 1258 ft. per sec.

Water catchers at the bases of the last two stationary rows are visible in Fig. 1. They are intended to remove a considerable portion of the moisture from the steam and bypass it direct to the condenser to improve the efficiency and reduce erosion. These last blades are protected by Stellite guards welded over the inlet edges and these shields can be renewed without disturbing the blades.

Turning Gear

An automatic motor driven turning gear is provided to rotate the spindle at about 3 r.p.m. while warming up. This is arranged to disengage automatically when steam is admitted and the speed increases. The cylinder itself is divided transversely into two parts, the high pressure portion being made of carbon-molybdenum steel. The exhaust end of the cylinder is supported by an integral type base extending around three sides of the exhaust opening and constructed so as to carry the entire weight of the condenser.

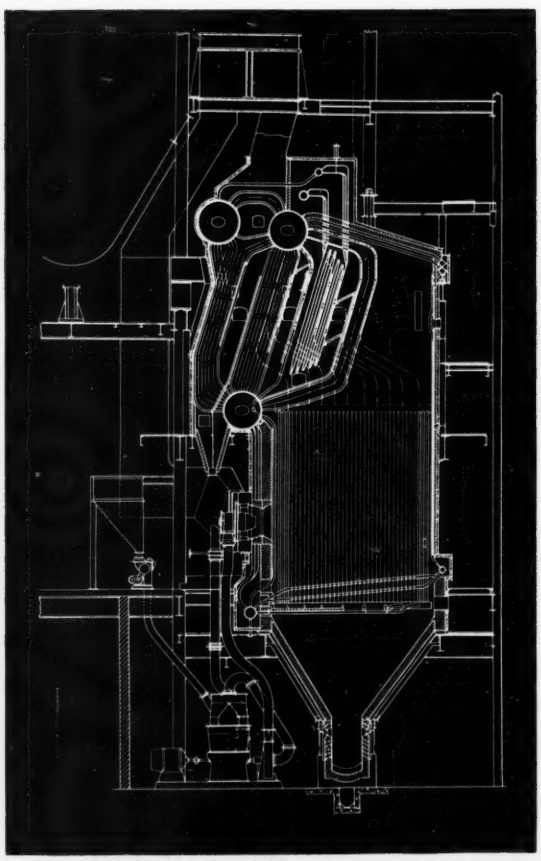


Fig. 3. Two boilers are installed. Each is fired by two unit mills and has a capacity of 130,000 lb. of steam per hr.

A.S.M.E. Holds 58th Annual Meeting

From December 6 to 9, Over 2200 Engineers Participated in a Program Devoted to Physical Sciences and Management and Their Application to Industry

YEAR BY YEAR engineers are growing more conscious of the human element as a controlling factor in the accomplishment of their industrial objectives, if one may judge from the program of the Fifty-eighth Annual Meeting of the American Society of Mechanical Engineers, held in New York City on December 6 to 9. People are human before they are engineers and it is not surprising that attendance gravitated towards the management sessions when such topics as the following were up for discussion: Labor's Attitude Toward Time and Motion Study; Maintenance Management and Control; Administration of the National Labor Relations Act; Problems in Unionized Plants; Practical Solutions to Problems in Labor Relations; and Apprenticeship Training. All of these subjects were given consideration in papers by eminent authorities representing employer and employee, educators and industrial engineers, social workers and government representatives.

Engineers have been accused of creating undesirable social conditions by their mechanization of industry. Without doubt they have lifted the physical burden from the backs of many laboring men. Can both men and machinery exist in our social order, or must a large portion of the human race continue, as in past ages, to make physical machines of themselves in order to eke out an existence? Engineers seem determined to find the answer.

Honors night, with President James H. Herron presiding, was held on Tuesday when R. Mervin Horn, of the Photographic Department of the Massachusetts Institute of Technology, delivered the Thurston Lecture on the subject, "Seeing the Unseen." Mr. Horn is one of the leading authorities on high speed photography and showed stills and motion pictures taken at the rate of 6000 frames per sec.

Recipients of Honors this year were: Lorenzo Allievi, to whom honorary membership was given for his outstanding work in connection with the problems of water hammer; Edwin P. Bullard, to whom the A.S.M.E. Medal was presented for his leadership in the development of station type of machine tools; Dr. Frederick G. Cottrell received the Holley Medal in recognition of his preeminent public service; C. F. Hirshfeld received the Warner Medal for his research and contributions to the theory and practice of heat-power engineering; Albert J. Buchi of Switzerland was given the Melville Medal, awarded on the basis of his paper, "Supercharging of Internal-Combustion Engines with Blowers Driven by Exhaust Gas Turbines"; The Junior Award went to Leslie J. Hooper, for his paper, "American Hydraulic Laboratory Practice"; the Undergraduate Student Award went to Gino J. Marinelli, for his paper on "Investigation of the Towing Resistance of a Model Submarine Hull," and to Allan P. Stern was given the Charles T. Main Award, for his paper, "Influence of Introduction of Labor-Saving Machinery Upon Employment in the United States."

Officers for the coming year were announced as follows: President Harvey N. Davis; Vice-Presidents Frank O. Hoagland, Bennett M. Brigman, Harte Cooke, Warren H. McBryde, and Lawrence W. Wallace; Managers Carl L. Bausch, Samuel B. Earle and Frank H. Prouty.

Harvey Nathaniel Davis, president of Stevens Institute of Technology, an engineer and scientist, was born at Providence, R. I., in 1881. He was graduated from Brown University with an A.B. degree in 1901 and, through postgraduate work, received his A.M. degree from Brown in 1902 and A.M. and Ph.D. degrees from Harvard University in 1903 and 1906, respectively. His professional career has been spent principally in educational positions at Brown, Harvard and Stevens. He has served, however, as consulting engineer for the Franklin Railway Supply and Air Reduction companies. In 1917-1918, he was in charge of the computation room at the Lynn, Mass., turbine plant of the General Electric Company. During the World War, Doctor Davis was active in the helium investigations that were conducted by the Army, the Navy, and the U. S. Bureau of Mines.

In addition to the "Tables and Diagrams of the Thermal Properties of Saturated and Superheated Steam," which he wrote in collaboration with L. S. Marks, Doctor Davis is the joint author, with H. N. Black, of "Practical Physics" and "New Practical Physics."

In 1928, Doctor Davis received the honorary degrees of LL.D. from Rutgers University and Sc.D. from Brown University. New York University conferred the honorary degree of Doctor of Engineering upon him in 1906.

Hotel Astor was the place of meeting for the Annual dinner, president's reception and dance on Wednesday evening. At this meeting Floyd Parsons presented his lecture entitled "What's Business Coming To" in which he pointed to numerous business opportunities brought about by recent invention and research. He warned, however, that "If the President and Congress keep the brakes clamped on until they burn out, the car will run wild. If the brakes are released we will save our skins. Instead of making progress, we have been moving steadily backward to the Elizabethan Age where personal initiative was strangled and freedom of speech and press unknown."

Earnest A. Hooten, Professor of Anthropology of Harvard University, presented the Towne Lecture at the dinner under the title "The Simian Basis of Human Mechanics, or Ape to Engineer," an extremely interesting history of the development of the human race, full of humor of a sort thoroughly appreciated by engineers.

All technical divisions of the Society were given full representation on the program with contributions of data on advanced research in mechanical engineering sciences and the application of new ideas to industry. Particularly popular among these sessions were those pertaining to steam power generation and fuels.

Reaching for the limit in steam pressure and temperature, engineers have encountered many problems in boiler design and operation. Contributing data on phases of these problems, four papers were presented at one power session. The approach of steam temperatures in industry to those used in the commercial production of hydrogen by reaction between steam and

HARVEY N. DAVIS

iron led to investigations at Purdue University of the oxidation by steam of the various steels that are available for high temperature steam service. These investigations were reported by Dean A. A. Potter, H. L. Solberg and G. A. Hawkins. Their work was conducted at temperatures up to 1200 deg. F. and pressures to 1600 lb. per sq. in. gage. The rate of oxidation of low-carbon steel at 1100 deg. F. is apparently the same at 400 and 1200 lb. pressure. This investigation required the development of considerable special apparatus which is being used in a continuation of this work.

Intercrystalline cracking of steels in water solutions was discussed by W. C. Schroeder; the decomposition of sodium-sulphite solutions at elevated temperatures has been under investigation at the University of Illinois and the results so far obtained were reported by F. G. Straub; results from research on flow nozzles carried on through the co-operation of the U. S. Bureau of Standards and the Ohio State University were included in a paper presented by title prepared by H. S. Bean and S. R. Beitler.

In another session consideration was given by William Hovgaard to studies made of three-dimensional pipe bends, and by R. B. Martin to the problem of chlorination of condenser water.

High temperature steam places severe strains on joints in piping and other containing vessels, as was brought out at this meeting in a number of papers devoted to progress in investigations of stresses in welded branch connections, pipe flanges subjected to creep, bolted joints, turbine cylinder joints and the effect of temperature variation on the creep strength of steels.

Research engineers have been at work on heat transfer problems relating to power equipment and some of the results were reported. In one report on investigation work conducted by Babcock & Wilcox Co. it was stated 38 arrangements of tubes were tested, differing in center-to-center spacing in the direction of flow and transversely. These tests demonstrated that both convection heat transfer and flow resistance of tube banks vary markedly with changes in tube arrangements and no simple statement of the variation is possible. It was also stated that the relation between the friction factor and the tube spacing is not the same as that for conductance of the gas boundary, and there is no consistent relation between pressure drop and heat-transfer rate. Report was also made on the experimental investigation of effects of equipment size on convection heat transfer and flow resistance in cross flow of gases over tube banks.

During recent months a number of high-pressure, high-temperature power plants have been put into operation. All of these contain features of unusual design with which there has been no experience to guide operators and it was with intense interest that our audience of engineers filling the auditorium listened to the men in charge of these plants tell of the troubles they have experienced during the starting up period of their plants and how these difficulties have been overcome. Strange as it may seem, considering the innovations in the designs of much of the equipment, nothing of so serious nature that it could not be readily corrected was reported. Some of the plants discussed were Springdale, Fisk, West End, Millers Ford, Logan, Omaha, Kansas City, 12th Street Station of Richmond, and Waterside.

Slag formation on the boiler tubes was a common complaint, giving superheat temperature trouble which was remedied by water wall changes, changes in fuel or slag tube arrangement. Seal welding was employed in some cases of leaks with boiler tubes rolled into headers and drums. Sticking safety valves were temporary worries in one plant, sensitive water level in another, circulation of water in furnace tubes needed correction in one design. Changes in baffles were common; turbine blades stripped by piece of metal in steam pipe; minor difficulties were encountered with pulverizing mills; hand hole gaskets replaced with metal type; deposits accumulated on turbine blades; initial difficulty was encountered in removing slag from wet bottom furnace; lighting off troubles with gas and kerosene were cured by turning to oil; incorrect water treatment was easily corrected. Not one serious accident was reported and the accuracy with which such guarantees as steam pressure and temperature, capacity, efficiency, heat release, draft losses and air preheat temperature was met is remarkable considering the

number of variables with which designers must deal and the pioneering nature of the work.

At the fuels sessions interesting data was presented on the operating results and recent installations of water cooled underfeed stokers. These stokers are being used with coal of the Midwest having ash that fuses at low temperatures and in furnaces equipped to burn gas and oil with results reputed to be highly satisfactory. W. J. Wohlenberg gave the development of a mathematical formula for the calculation of the energy distribution in the pulverized coal furnace cavity and practical methods of dealing with slag encountered in boilers and furnaces were discussed by A. D. Bailey and J. D. O'Brien. Mr. Bailey stated that slagging trouble has increased as the capacity and efficiency of steam-generating equipment have been increased. Since the character of the fuel is such that the cause cannot be removed before the coal is burned without destroying the coal itself, slagging is generally accepted as a necessary evil. The design of steam-generating equipment is gradually being changed so that it will be better adapted to the coal to be burned, give less slagging trouble, and stay in service for longer periods. Reducing the ash content of the coal by washing or any other means is, of course, advantageous, but the chemical treatment of coal with a view to eliminating slagging troubles or reducing them has been generally unsuccessful.

R. A. Sherman presented a progress report on the comprehensive investigation of the factors involved in the treatment of coal with petroleum products. Despite the rather wide use of light petroleum oils for several years, and the less-extended use of heavier oils and petrolatum in more recent years, quantitative data have been lacking on the relation of the type of oil and the amount of oil to the effectiveness and permanence of treatment. Data presented for five different oils, for one petrolatum, and on coal from two typical seams. Data were also given showing the effect of oil treatment on segregation of coal in small stokers. Tests are still under way to show the effect of oil treatment on oxidation and spontaneous combustion.

X-Ray Examination of Castings

Limitations of this method of examination depend primarily upon lack of experience in reading the negatives and the high cost*

RADIOGRAPHS are shadow pictures of material more or less transparent to radiation. The x-rays darken the film so that regions of lower density, which readily permit penetration, appear dark on the negative in comparison with areas of higher density which absorb more of the radiation. Thus, cavities in metals are recorded as darker areas, while heavy inclusions, such as iron scale or copper segregation in an aluminum alloy, register a correspondingly lighter region on the radiograph.

In castings, differences in thickness due to the form, and intentional cavities, as cored holes, are regions of low density and are revealed as darkened areas. Castings containing variations in thickness caused by the unintentional absence of metal also result in darkening of the film. Excess metal and inclusions more dense than the base metal appear as light regions. The casting discontinuities of the latter two types may be recognized on the negative by the following characteristics:

Reading the Film

Surface roughness appears as white or dark irregular areas with a smooth contour. The coloration depends, of course, on whether the surface protrudes or is depressed. The surface irregularities must be carefully compared with the radiograph and identified before an attempt is made to interpret the internal discontinuities.

Gas cavities, blowholes and minute pinhole porosity appear as well-defined spherical or rounded darkened areas.

Shrinkage, pipe and shrinkage porosity are represented by filamentary or dendritic dark regions of irregular dimensions and indistinct outline.

Cold shuts appears as very prominent darkened areas of variable dimensions with definite, smooth outlines where the molten metal failed to unite completely before solidification.

Cracks are represented by darkened lines of variable width and are filamentary when derived from insufficient feeding or contraction (shrinkage) on cooling from the melt. Cracks originating from internal stress in solid metal are either angular or straight and are of more constant width.

Sand inclusions occur as gray to black spots on an uneven or granular texture with indistinct extremities.

Inclusions such as copper or iron segregation, and foreign matter of greater density than aluminum occur as well defined, white areas. Dross inclusions appear as darkened regions of irregular and indistinct outline on the radiograph. The darkened area generally varies in intensity, indicating variations in the quantity of aluminum oxide and air.

Experience Necessary

The present principal disadvantage of radiographic examination is the lack of experience on which to base a correlation of structure, as revealed by radiography and service life. Practically any properly made radiograph of a commercial casting will reveal discontinuities of structure, and a great deal of judgment must be exercised in using radiography as an inspection tool. The foundryman has made good use of radiography to improve his technique; it remains for the user of castings to equal this diligence by establishing a background of experience in relating radiographic structure to service life. A minor disadvantage of radiographic inspection of castings is its cost. This is usually expressed in terms of area of film and is generally within the range $1.00 to $3.00 per sq. ft.

* Taken from a paper, Quality Control of Aluminum Alloy Aircraft Castings, by Kent R. Van Horn and Howard J. Heath, both of the Aluminum Company of America, presented before the S. A. E.

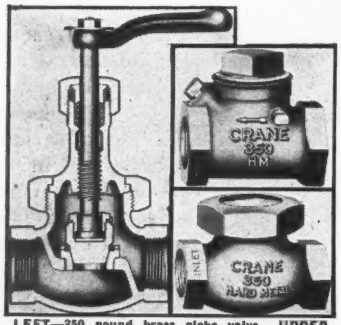
New Equipment

Information that you desire about any equipment will be gladly furnished without obligation. WRITE POWER PLANT ENGINEERING.

Brass Valves for 350 lb. Steam

BRASS SCREWED and globe and check valves for 350 lb. steam pressure at 550 deg. F. temperature are now being offered by Crane Co., Chicago, Ill. These valves are designed especially for high pressure steam lines such as are used on oil and gas field boilers for deep well drilling operations. They also may be used on non-shock cold water, oil or gas lines up to 1000 lb. Their sizes range from ½-in. to 2-in.

The globe pattern brass valve is of the union bonnet design (except the 2-in. which has a bolted bonnet) and has Crane nickel alloy plug type disc and Exelloy body seat ring. The stuffing box is supplied with a gland and is filled with high grade packing which may be replenished when the valve is wide open and under pressure.



LEFT—350 pound brass globe valve. UPPER RIGHT—350 pound brass swing check valve. LOWER RIGHT—350 pound brass lift check valve.

The horizontal lift check valve also has a union bonnet except the 2-in., which has a bolted cap. Discs are of the piston-guided type and seats are renewable screwed in rings of Crane nickel alloy. The horizontal swing check valve which may be used either for horizontal or upward flow, has screwed cap and tapped hole in the body to facilitate regrinding of the disc.

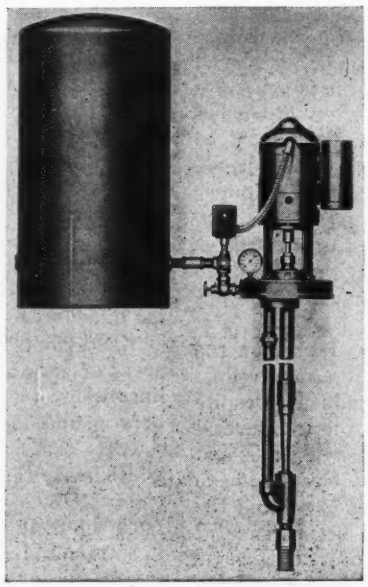
In order to have a companion line of brass gate valves for this same service, a 350 lb. steam rating at 550 deg. F. has been added to the regular Crane No. 230-H brass gate valves.

Vertical Centrifugal Pump

NEW VERTICAL, close-coupled motor-driven centrifugal pumps for general service in deep or shallow wells have been announced by Fairbanks, Morse & Co., 900 S. Wabash Ave., Chicago, Ill. This new pump was designed to meet the recognized need for a small-diameter, low-capacity, dependable pump with low initial and operating costs. It is ideal for economically pumping water under either high or low pressure at 6 to 60 g.p.m.

Units for shallow well service consist of combined motor, pump and base, into the bottom of which is screwed a single suction pipe extending below the water level. This is satisfactory for water lifts of 15 to 20 ft.

For wells of 20 to 200 ft. deep, pumps are equipped with an ejector and venturi in one of two drop pipes extending from the pump down into the well. This deep-well pump operates on the accepted prin-



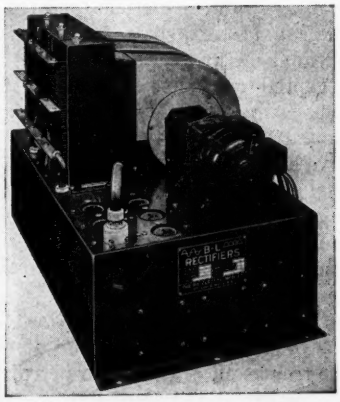
ciple of the centrifugal pump, with the ejector added to lift water from depths beyond that from which a centrifugal pump alone will lift it. By allowing a predetermined amount of water from the pump discharge to bypass down one of the drop pipes in the well and back up through the ejector into the venturi, a vacuum is created above the ejector nozzle, drawing well water into the suction chamber. The high velocity of the water through the venturi, and the mixing of the two streams of water, lifts the well water to within reach of the pump suction.

High Capacity Battery Charger

THE B-L ELECTRIC MFG. CO., St. Louis, Mo., announces the development of a new type of heavy duty battery charger which is designed for charging all large capacity batteries, as, for instance, those used in industrial electric trucks. This new design embodies metallic rectifier units, which have been further improved by recent developments that make practicable the rectification of large currents with very compact units.

The unit may be mounted in any convenient location, or supplied in a portable type with rubber-tired wheels. The charger is ready for immediate operation wherever a three-phase 220-v. line is available.

A heavy metal base houses the transformer which supplies the rectifier units. Mounted above the transformer, on top of the base, is a three-gang centrifugal blower driven by a ball-bearing motor to which it is directly coupled. This blower propels air at a relatively high velocity directly through the radiating fins of the three rectifier stacks.

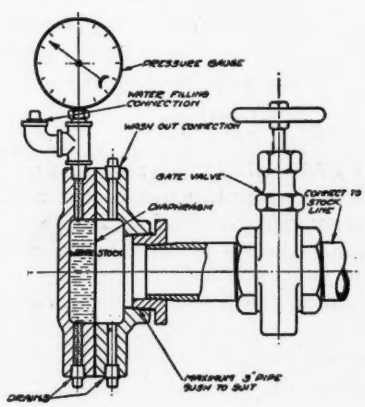


The average charging rate of this unit is about 100 amperes for a lead-acid battery of 16 cells, or a nickel iron battery of 25 cells. Other sizes are available to meet varying requirements.

Stockline Diaphragm Gauge Connection

MEASUREMENT OF PRESSURES existing in pipe lines handling water and other thin liquids means simply the attachment of a pressure gauge. When handling paper stock or other liquids containing materials of a fibrous nature, this method is not satisfactory because the fibrous material will quickly plug the opening into the gauge.

To overcome this difficulty, Goulds have developed a "Stockline" Diaphragm Type Gauge Connection which will give accurate readings of the pressure in such lines.



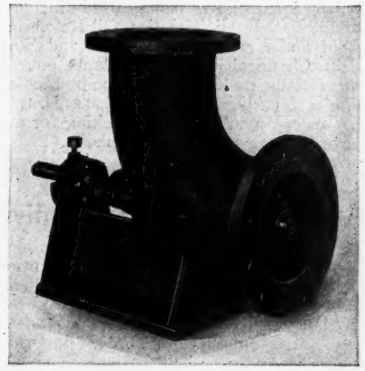
It consists of two recessed circular flanges with a thin flexible diaphragm between them. One flange is tapped for 3-in. pipe connection, and can be attached through nipples and gate valve to the stock-line or other pipe. There is a tee and filling connection between the outer flanged section and the pressure gauge.

In use, the space between the diaphragm and outer flange section should be completely filled with water to avoid rupture of the diaphragm.

When the gate valve is opened, the pressure of the stock or other thick fibrous material acts on one side of the diaphragm, which transmits the pressure to the water on the opposite side, thus recording the exact pressure on the gauge without the material coming in contact with the fluid actuating the gauge. Exact pressure readings are thus obtained.

Elbow-Propeller Type Pump

A NEW LINE of elbow-propeller type circulating pumps to handle not only water but also semi-viscous liquids, especially liquors, sugar juices, paper stock, and the like, is offered by Worthington Pump and Machinery Corp., Harrison, N. J.



These new pumps, compact and sturdy in design, may be installed in pipe lines for booster or circulating service, the small number of vanes and large openings providing a large streamline flow channel. Internal bearings and ball-type thrust bearings are provided and the units are suitable for any type of drive. They range in capacity from 1,000 to 2,000 g.p.m., at heads up to 20 feet.

Power Pumps

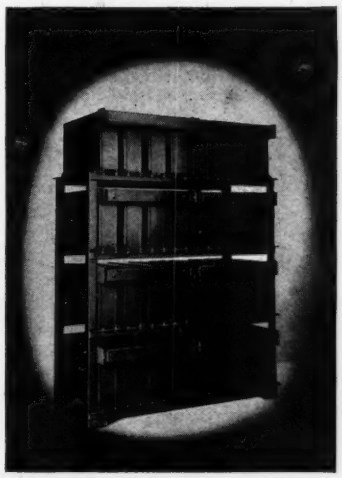
FAIRBANKS, MORSE & Co., Chicago, Ill., has developed a new line of duplex power pumps, Fig. 6130, for oil field service, fire protection and for general service requiring pressures up to 800 lb. per sq. in. and capacities to 187 g.p.m.

Among the features are: Herringbone gears to insure a smooth flow of power to the fluid end; generous crank-shaft and pinion-shaft roller bearings to reduce mechanical friction to a minimum; and an improved line type fluid end. Because of their positive displacement design and operating principle, power pumps are more suitable than other types for certain conditions and requirements. In handling heavy or viscous liquids, the speed of the power pump can be reduced to effectively accommodate slow-flowing characteristics. Cylinders are filled on each piston stroke, and the pump performs at its maximum efficiency.

F-M Fig. 6130 power pumps are offered with a fluid end piston stroke of 10 inches and with cylinder diameters of 2½ to 5 inches, providing a capacity range of 40 to 187 U. S. gallons per minute at pressures from 250 to 800 lb. per sq. in. The pumps can be furnished alone, with pulley for belt drive, or with top-mounted F-M motor and silent chain drive.

Box Type Capacitors

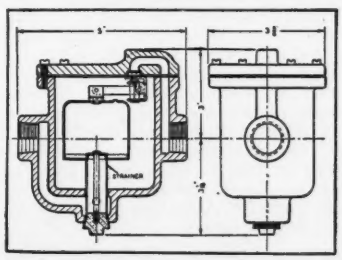
THESE UNITS for power factor correction are now made in box type, completely assembled and wired for convenient installation and connection for



all voltages and capacities. Illustrated is the unit for 640 kv-a. at 460 v., 3-phase and 60 cycles. Cornell-Dubilier Electric Corp., So. Plainfield, N. J.

Inverted Bucket Trap

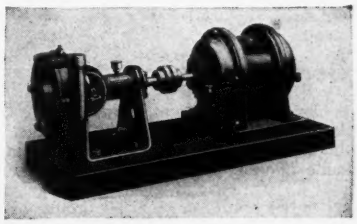
OF NEW STRAIGHTWAY type, with connections arranged on opposite sides of the body on the same center line, this trap is made in one size with ⅜ or ½-in. outlet. All mechanism is attached to the cover and can be removed without disturbing piping.



The bucket is inverted and strainer is built in. The straight-through connection is designed to simplify pipe connections. With cast iron body, maximum pressure is 125 lb. and maximum capacity 990 lb. per hr. at 50 lb. With semi-steel body, maximum pressure is 250 lb. and maximum capacity 350 lb. per hr. at 175 lb. It is made by Sarco Co., Inc., New York, N. Y.

Pressed Steel Frame Mounted Pumps

A NEW LINE of pressed steel frame mounted ball-bearing centrifugal pumps is announced by Worthington Pump and Machinery Corp., Harrison, N. J. Available for belt or motor drive, these type CF pumps are suitable for handling capacities from 10 g.p.m. to 300 g.p.m., at heads from 10 ft. to 120 ft.

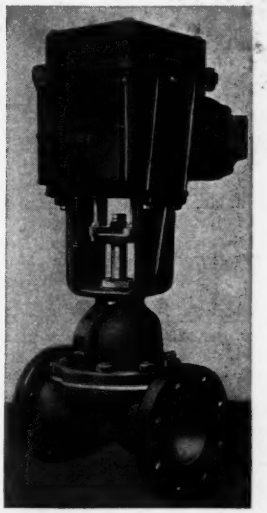


Stronger than iron and yet ductile enough to withstand vibration, shock and distortion is the Worthington description for the new YU type pressed steel frame.

Equipped with two grease-lubricated ball bearings, these modern single-stage units should serve a wide range of uses.

Motor Valve Operation

DESIGNED TO OPERATE slip-stem valves for heavy pressures and in large sizes, this mechanism exerts a force of 2000 lb. over 2½ in. to 10 in. stroke at speeds of 3 to 10 in. per min. The illustration shows



a type for 2½ in. stroke at 5 in. per min. mounted on a 4-in., 150-lb. Saunders patent valve. Power release control permits positioning the valve at any definite open and closed points regardless of motor drift. Control may be for full open and closed operation or for automatic control to intermediate positions proportional to a variable such as temperature or pressure.

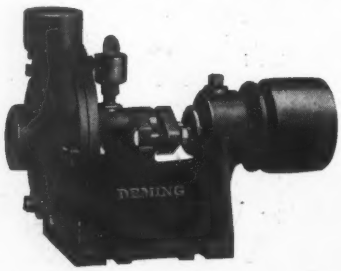
This type, known as Model C, has been added to its line by Automatic Temperature Control Co., Inc., Philadelphia, Pa.

Mild Steel Electrode

THE LINCOLN ELECTRIC CO. of Cleveland, Ohio, announces a new mild steel arc welding electrode designated as Transweld for use with small alternating-current-transformer type arc welders. It has a heavy extruded coating, is stated to produce a stable arc making smooth, well shaped beads in the welds and has a tensile strength of 75,000 to 85,000 lb. per sq. in., yield point 60,000 to 68,000 lb. per sq. in., and ductility 20 to 30 per cent elongation in 2 in. It is made in three sizes, $\frac{3}{32}$, $\frac{1}{8}$ and $\frac{5}{32}$ in. diameter.

Centrifugal Pump

AS MANUFACTURED by the Deming Co., Salem, O., Fig. 3900 is a side suction, single ball bearing type centrifugal pump, made in two sizes: ½-in. discharge with a ¾-in. suction and ¾-in. discharge with a 1-in. suction. Standard all bronze or all iron fitted construction is available. For

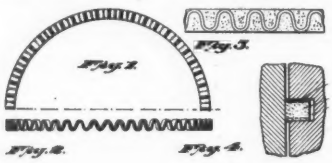


direct connection to motors the pumps are suitable for speeds up to 350 r.p.m., for belt drives for speed up to 3000 r.p.m. When motor driven the complete unit is mounted on a cast iron base except in the case of the ¾-hp., 3425 r.p.m. motor unit with which a steel channel iron base is furnished. Either type pump may be used with a direct connected gasoline engine drive.

New Piston Ring

PISTON RINGS of a new type, patented and suitable for use in internal combustion engines, air compressors, pumps, steam engines or even as packing, have been developed by the Elk Machine & Tool Wks., 109 West 64th St., New York, N. Y.

Figure 1 is a plan, and Fig. 2 a side, view of the ring. The body of the ring is made of a resilient metal strip corrugated, bent into a circle with a plastic material, as shown in Fig. 3, molded into the body. This plastic material acts as a filler to completely occupy the space in the piston ring groove. The filler and body



thus forms a solid integral open band which is wrapped around the piston ring groove as shown in section at Fig. 4. The open ends of the corrugation are nested together, as shown near the center of Fig. 2. These end corrugations being made slightly narrower vertically, where nested together, just fill the groove.

Both the metal and the plastic material make a contact and bearing surface, not only with the cylinder wall but with the upper and lower faces of the piston ring groove. As the ring is compressed radially, obviously it tries to expand vertically in its slot, thus completely filling the groove as shown in Fig. 4. Varying the alloy of the metal used, or the number of corrugations per inch, or the thickness of the metal, makes possible any desirable wall tension the design calls for.

The manufacturer states that under no conditions, regardless of temperature or the absence of oil, would this piston ring freeze or cause scoring. The reason he gives for his contention is that the plastic material not only expands and compresses with the corrugated body but it has lubricating qualities as well.

Hancock Blowoff Valve

ANNOUNCEMENT comes from the Hancock Valve Division of Manning, Maxwell & Moore, Inc., Bridgeport, Conn., that a full new line of boiler blowoff valves is now available. This new line incorporates a number of features including the Blo-Deflector protecting lip. This design principle deflects boiler blow in such a way

as to protect the disc and seat. To further increase the wear-resistance of these valves, they have stainless steel valve discs hardened to 500 Brinell and renewable valve seat rings heavily Stellited. Simplicity of design and fewness of parts are other features of these valves. The illustration shows the Blo-Deflector protecting lip on the 500 Brinell stainless steel valve disc.

These new Hancock blowoff valves are made in both straightway and angle types for boiler and economizer pressures up to 1660 lb. in full compliance with A. S. M. E. code requirements.

M. S. A. Explosimeter

MINE SAFETY APPLIANCES COMPANY, Braddock, Thomas and Meade Streets, Pittsburgh, Pa., recently placed on the market the M. S. A. Explosimeter, a pocket-sized instrument for quickly and easily determining the presence of combustible gas hazards.

This instrument is designed to meet the demand of operating men for an instrument that can be carried about on the job and operated by any workman. It shows whether gas concentrations are within or above the explosive range. In size and weight, the M. S. A. Explosimeter compares with a small folding camera, and can be carried either in a pocket or on a shoulder strap.

Dependability, compactness and easy operation give the Explosimeter a wide range of application. Some of the fields in which it is now being used include; Distilleries, Public Utilities, Oil Refineries, Paint and Varnish Plants, Iron and Steel Mills, Chemical By-product Plants, etc. It is especially well adapted to use by municipalities for investigating fire hazards, testing sewers, manholes and checking for gas hazards in sewage disposal plants.

A New Corrosion Preventive

A NEW DEVELOPMENT in the prevention of corrosion in steam systems is embodied in the product Coravol, offered by the Western Chemical Co., Kansas City, Mo., under a recently patented process.

When Coravol, a liquid treatment, is fed into the boiler, it dissolves in the boiled water, volatilizes with the steam, condenses with the steam, and forms a solution in the condensate, so that all parts of the system are maintained in an alkaline range. It neutralizes and absorbs carbon dioxide, and raises the pH of the condensate. It provides the vapor and condensate zones with the same protection formerly available to the boiler only.

Coravol is not a boiler feedwater treatment and does not take the place of one. It reaches those parts of the system not accessible to boiler feedwater treatment. Assuming that the boiler water is maintained in a properly treated condition, then the entire action of Coravol is devoted to neutralizing carbon dioxide and prevention of corrosion in the steam and return lines, and the boiler above the water line, which are not reached by other methods.

Coravol has a cyclic action whereby it circulates continuously from the boiler, through the lines, and back to the boiler. After the proper alkilinity in the system has been built up, only enough Coravol need be added from time to time to replace that lost from the system, controlling the dosage by means of a special testing set furnished with the material. In the operation of boilers having a low percentage of make-up, dosages are particularly low and economical.

Prevents Air Line Freezing

AIR LINE FREEZE PREVENTION known as Frosto is being marketed by Sullivan Machinery Co. to supplement Tanner Gas. It has been developed for industrial applications wherever electric current is available and is fed through a vaporizer into the compressed air line near the compressor. Current consumption is said to be small and a quart of Frosto is required to treat 100,000 cu. ft. of free air. It is distributed by the Sullivan Machinery Co., Michigan City, Indiana.

Design and Development Engineers

ALBERT F. SPITZGLASS, formerly vice-president in charge of engineering, and Maurice J. Zucrow, formerly director of research of the Republic Flow Meters Co., recently announced the opening of offices and laboratories at 415 N. La Salle St., Chicago, Ill. They will conduct a consulting engineering practice and specialize in the design and development of new products.

Heating and Ventilating Exposition in New York

WINTER HEATING of homes, public buildings, and factories, and air-conditioning on a year 'round basis are themes which will be coordinated and amplified at the Fifth International Heating and Ventilating Exposition. This event will be held at Grand Central Palace, New York, during the week of January 24 to 28, 1938. It will be under the auspices of the American Society of Heating and Ventilating Engineers, whose 44th annual meeting will be held during this same week in New York.

Furnaces, burners, and boilers will constitute an important section of the exposition. They will be demonstrated in terms of the advantages of the various fuels used in their operation—coal, gas, and oil. Everywhere the tendency toward fuel economy and streamlined cabinet design will be emphasized. In contrast to the early years of the industry, one manufacturer of boilers, for oil, gas, stoker or hand firing, calls attention to new jacketed design decorated in two-tone blue with red striping. Burner units in practically all sizes reflect the trends to efficiency and economy of operation and condensed modern construction.

20,000-Kw. Plant for Venezuela

THE J. G. WHITE Engineering Corp., New York, has been awarded a contract for the design and construction of a 20,000 kw. power plant for The Venezuelan Oil Concessions, Limited, a subsidary company of the Royal Dutch-Shell group, operating in Venezuela.

The boilers in the new plant are designed to be operated either with natural gas or oil from the adjacent oil fields, and as this fuel is of low cost, the station is designed primarily for simplicity and reliability and of moderate first cost. A 1500 ft. channel is being dredged to deep water in the lake for a suitable supply of condensing water. The waters of Lake Maracaibo are brackish and a special evaporating plant has been designed to provide make-up water for the boilers. The distribution of power from the plant to the oil wells is provided by means of a 33,000 v. double circuit steel tower transmission line thirty-five miles long. The oil wells are located along the length of the line and the high tension power from the transmission line will be reduced in eight substations for local distribution and to service transformers for small adjacent groups of wells.

The four 5000 kw. turbo-generators and the four 1000 hp. boilers, as well as practically all machinery and materials, are being manufactured in the United States. The J. G. White Engineering Corporation is in charge of the engineering design, purchasing and construction.

Utility to Spend Over 3 Million on 1938 Construction

J. P. PULLIAM, president of the Wisconsin Public Service Corporation, has announced the approval of the corporation's 1938 construction budget totalling $3,310,699. This proposed budget is more than double that of last year and is indicative of the company's desire to assist in the stimulation of business.

Included in the 1938 budget is an appropriation for the construction of a new hydro-electric plant to be erected on the Wisconsin River between Merrill and Tomahawk. This new plant will have a capacity of 17,500 kilowatts and will cost approximately $1,675,000 including necessary substations and the construction of a 32-mile 66,000 volt transmission line from Wausau to the new plant.

Also included in the budget are projects covering improvements to the company's steam plant at Manitowoc, amounting to approximately $100,000 and provisions for inter-connection of the company's system which will require expenditures of about $65,000.

Improvements and changes in present steam plants will cost about $115,000 and changes in hydro plants will amount to around $100,000. Gas plant and gas distribution additions and changes will cost $80,000. Transmission line additions and changes will cost approximately $200,000 and improvements in sub-stations will require more than $375,000.

Approximately $800,000 will be spent for new distribution lines in the territory served by the company and more than $500,000 of this amount will be spent for new rural line extensions.

F-M Diesel Sales

APPOINTMENT of T. M. Robie as manager of the Diesel sales division of Fairbanks, Morse & Co., has been announced by A. C. Dodge, vice-president in charge of sales. Mr. Robie has been associated with Fairbanks-Morse in numerous capacities in the manufacturing and sales division since he returned from World War overseas service in 1919. Since 1932 he had been in charge of Diesel sales to resale manufacturers. Previously, he was associated with the New York branch office for one year and the Dallas office for two years, and was employed at the factory on Diesel engine designing, testing and building for nine years. Upon his graduation from the University of Michigan in 1914, where he specialized in the study of internal combustion engines, Mr. Robie was employed by General Electric Co. on locomotive test

T. M. ROBIE

and on development of high-speed opposed-piston Diesel generating sets for stationary and Diesel-electric railway locomotive application. He operated Diesel power plants in New Mexico for two years previous to entering war service.

News from the Field

ADDITIONAL exclusive representatives have recently been appointed for the sale of Roots-Connersville turbine pumps, according to an announcement just released by J. B. Trotman, manager of the Turbine Pump Division of the Roots-Connersville Blower Corp., of Connersville, Ind.

Arthur N. Goff, 94 Eighth St., Fond du Lac, Wis., who has three salesmen associated with him, will cover Wisconsin with the exception of a few counties comprising the Milwaukee area.

F. W. Bartling and G. T. Oberklein, 950 E. Court St., Cincinnati, Ohio, will cover the southwestern section of Ohio, as well as the counties in north-central Kentucky, as far south as Lexington, and a few adjacent counties in Indiana. Mr. Bartling will concentrate on jobber distribution, and Mr. Oberklein will develop industrial sales.

E. G. BAILEY, vice-president of The Babcock & Wilcox Co., has been given the honorary degree of Doctor of Engineering by Lehigh University for "notable and distinguished accomplishment in the field of combustion and steam engineering."

HENRY C. HILL, 132 Wyoming Ave., Cincinnati, O., has been appointed sales representative of Beaumont Birch Co. for the sale of their complete line of coal, coke and ash handling equipment.

C. O. MESSENGER, formerly sales representative in Ohio and Michigan for Cabin Creek Consolidated Sales Co., is now assistant to the vice-president of that company, located in Cincinnati.

YORK ICE MACHINERY CORP. recently held its 25-year-Club banquet with more than 250 present who have had 25 yr. or more continuous service with the organization. The longest record was Frank H. Schlosser, 49 yr. Officers elected were: President, Norman Landis; vice-president, Luther Bond; secretary, Lea Becker; treasurer, F. Marion Dick.

R. E. Howe, president of Appalachian Coals, Inc., has been elected to the board of directors of Bituminous Coal Research, Inc., a fact-finding unit of which ACI was one of the sponsors. Also on the board is M. L. Patton, vice-president of Cabin Creek Consolidated Sales Co., and on the technical advisory board which outlines the experimental work to be done, is J. E. Tobey, manager of the fuels engineering division of ACI.

H. P. Hood & Sons Co., Charlestown, Mass., is constructing a new boiler plant of glass brick in which two 415-hp. Babcock & Wilcox bent tube boilers are to be installed. This plant will be considered the last word in plant design in the Dairy Industry.

New smoke ordinance in St. Louis requires every coal merchant to secure a permit, every coal delivery vehicle to be registered, all coal 2 in. or under with ash over 12 per cent or sulphur over 2 per cent to be cleaned so that ash is not more than 12 per cent, all coal over 2 in. to be hand picked so that visible impurities are not over ¾ of 1 per cent. Other provisions are much the same as for smoke ordinances throughout the country.

E. P. Kramer, Atlanta, Ga., has been chosen chairman of the Gas Engine Power Committee of the Industrial Gas Section of the American Gas Assn.; Ralph H. Wenner of Toledo, O., is vice-chairman.

A. A. Nelson is now a member of the sales force of the Robins Conveying Belt Co., New York, N. Y., covering a territory which comprises the Eastern end of New York State and the Western part of Connecticut.

Allis-Chalmers Mfg. Co. has opened a sales office in Syracuse, N. Y., at 943 West Genessee Street, with George H. Carden as sales engineer-in-charge. This office will operate as a branch of the company's Buffalo district office of which H. E. Weiss is manager.

Appointment of W. E. Wechter as Manager of Oil and Gas Engine Sales, Atlantic Division, is announced by Worthington Pump and Machinery Corp. Mr. Wechter succeeds R. L. Howes, recently resigned. In his new duties, Mr. Wechter will supervise oil and gas engine sales in the Atlantic seaboard territory, in which are the Worthington offices at Boston, New York, Philadelphia, Washington and Atlanta. He will make his headquarters at the Worthington office, 2 Park Ave., New York City.

One of the best known engineers in the refrigeration industry and a recognized authority on refrigerating machine design, N. M. (Scotty) Small, for 34 years a member of the Engineering Department of Frick Co. at Waynesboro, Pa., passed away on November 28th. He had been in ill health for the last two or three years. Mr. Small was born at St. Thomas, Pa., and took his degree in mechanical engineering at Pennsylvania State College. He served in various capacities at Frick Co., was made chief engineer of the Refrigerating Machinery Department in 1922 and in 1935 became consulting engineer for the Frick Co.

Erving A. Lueky, since 1914 superintendent of the demand and construction division of the Detroit Edison Co., died at his home in Detroit Nov. 20. Born in Detroit, he began with the Edison Co., 37 years ago as a meter reader. He is credited with several inventions which improved the meter.

William M. Smith, St. Johns, Mich., retired chairman of the Michigan Public Utilities Commission, was killed in an automoble collision Nov. 20 near East Lansing. He was the first chairman of the commission when it was created in 1919 and served until 1923. He was reappointed in 1935, resigning two years later.

Murphy Diesel Co., Ltd., Milwaukee, Wis., recently announced the appointment of George P. Hough as Sales Manager. He graduated from the University of Minnesota and was admitted to the bar in 1920. Since then he has had a wide and varied experience in general merchandising and in the manufacture of heavy equipment.

John B. Goddard, electrical engineer for the West Virginia Public Service Commission, died at a Charleston hospital Dec. 4. He graduated from Ohio State University with an engineering degree in 1929, and joined the commission as an engineering assistant in 1934. During his short service he was promoted several times. He was a member of Phi Kappa Tau, Tau Beta Pi, Eta Kappa Nu and American Institute of Electrical Engineers.

Ernest W. Mallory, who in 1916 built the St. Marys Power & Light Co. plant, died at a Parkersburg hospital Nov. 26. He owned and operated the plant until 1924 when he sold it to the Monongahela West Penn Co.

American Transformer Co. has completed its new plant at 273 to 301 Emmet St., Newark, N. J., where it will manufacture heavy industrial transformers, according to Thomas M. Hunter, president. The general offices and factories for the manufacture of smaller transformers will remain at the present location—172-180 Emmet St.

Thomas Fitzhugh, chairman of the Arkansas Utilities Commission, has been appointed to the rural electrification committee of the National Association of Railway and Utilities Commissioners.

Myron James Cavers, Noranda, Que., has been appointed a member of the National Electricity Syndicate, created by the Quebec legislature to enable the provincial legislature to undertake hydro-electric development.

Murray F. Gill, Wichita, Kans., assistant to the president of the Kansas Gas & Electric Co., was elected to the board of directors at a meeting held recently in Kansas City, Mo.

Marshall E. Lake, of the Duke Power Co., Charlotte, was elected chairman of the North Carolina section of the American Institute of Electrical Engineers at its fall meeting at Duke University Dec. 3.

Ray Phillips Jackson, Wilkinsburg, Pa., engineering representative of the patent department of the Westinghouse Electric Manufacturing Co., died Nov. 27 while on a business trip to North Philadelphia. Born near Traverse City, Mich., he graduated from the engineering school of the University of Michigan and immediately joined the Westinghouse Co. He held positions of material and process engineering manager and Emeryville, Cal., plant manager before joining the patent department.

Charles H. Champlain, former general works manager for the main plant of the Westinghouse Electric & Manufacturing Co. at East Pittsburgh, Pa., died at his home Dec. 2. He retired three years ago because of ill health. He joined the company in the 1890's and in 1903 was placed in charge of the manufacture of railway transportation rotating equipment and later was made general foreman in the manufacture of industrial governors. After the World War he became assistant works manager of the East Pittsburgh plant. Four years later the company sent him to Sharon to supervise construction of a new plant for manufacturing transformers. He became manager of the plant and remained until 1931 when he was made general works manager of the East Pittsburgh plant.

For the Engineer's Library

Any Catalogs that you wish will be gladly sent. Write Power Plant Engineering.

Controls, Meters and Instruments

Pyrometer Controllers.—Close electrical control—free from chattering at the contact points—is provided through Bristol's new Pyromaster Pyrometer Controller. This instrument is one of a new line of round-chart potentiometer pyrometers, manufactured by The Bristol Co.

Pyromaster Electric-Type Controllers are equipped with special "Unitact" relays, which require the making and breaking of only one contact, as the name implies, to effect control. They may also be built to operate with standard relays that require contacts for both making and breaking the controlled circuit. The new feature offered by "Unitact" control is in providing for quicker response to changes in the controlled temperature and in eliminating insecure contact at the control points.

It is the new operating principle of Bristol's Pyromaster that makes "Unitact" control possible. Instead of continuously moving parts and trains of gears to be engaged and released as with ordinary potentiometers, a series of relay-actuated switches, with a special wiring arrangement, is used to position the pen arm on the instrument chart and to effect control. The same types of control are obtained with the Pyromaster "Unitact" Controller as with standard relays, that is, High, Low, High-Low, High-Off-Low, and High-Normal-Low.

Bristol's Pyromaster instruments—the recorders, controllers and indicators—are compact in construction, being built in standard 12-inch cases; they are rugged and not affected by plant vibration; they have no continuously moving parts; they require no lubrication. The Bristol Co., Waterbury, Conn.

Weather Instruments — Indicating and recording instruments for temperature and relative humidity, also equipment for wind direction and velocity are described in Catalog No. 6 of Julien P. Friez & Sons, Inc., Baltimore St. and Central Ave., Baltimore, Md. Copies are available to those particularly interested in such work, who write on business letterheads.

Electrical Instruments.—The various improvements recently made in Bristol's Recording Voltmeters and Ammeters are outlined in a new bulletin now available through the main office of The Bristol Company, Waterbury, Conn. Sample chart records and photographs of the new instrument models, showing the compact and simple operating mechanism, are included in the bulletin.

Interesting facts are also given regarding the usefulness and the various applications of these instruments in such industries as: public utilities, chemical, ceramics, rubber and plastics, pulp and paper, food, and dairy.

A copy of Bulletin No. 496 on Bristol's Modern Electric Recorders, may be obtained upon request to The Bristol Co., Waterbury, Conn.

Electrically Controlled Valves—A miniature appearing text book entitled "Controlling Valves Electrically" has recently been issued by The Automatic Switch Co., 154 Grand St., New York, N. Y.

Recording Thermometers is the subject of bulletin 198-1. A brief story on the value of thermometers is followed by separate descriptions of the thermometers associated with the Foxboro trade mark. The story of each class is complete and continuous. Its appearance, its range characteristics, its thermal system and its special bulbs are all illustrated and described within the limits of four pages. The same plan is followed for other sections of information.—The Foxboro Co., Foxboro, Mass.

Now, All Foxboro Instruments Are Certified—This new 16-page folder describes the significance of the seal of certification which is now attached to every Foxboro instrument. The folder also contains illustrations of more than twenty instruments which are representative of the entire line. Separate sections discuss thermometers, pyrometers, controllers for pressure, temperature and flow; Rotax (electric) controllers; Stabilog controllers; pressure gauges; liquid level gauges; flow meters; flow controllers; humidity instruments; and portables and tachometers. It is issued by The Foxboro Co., Foxboro, Mass.

Hays Combustion Instruments are discussed in three new bulletins recently issued by the company. Bulletin 105, entitled Excess Air, explains the use of the Hays Draftrol and gives the relation of air to fuel in the process of combustion. Losses caused by improper draft are explained in detail. Hays Draft Gages is the title of bulletin 37-294 which describes and illustrates this piece of equipment. Bulletin 37-297 is a treatise on Hays Combustion Instruments which explains the use of the Orsat principle in connection with the instrument. The Hays Corp., Michigan City, Ind.

Flow Meters for 1500 lbs. Working Pressure—This new bulletin describes special flow meters for high pressure measurement. A sectional view of the Type 7000 meter shows the forged steel chambers, recessed and serrated gasket surfaces, bearing lubricator, Pressur-Tite bearing, patented chain and segment drive, positive acting check valves and threaded and welded joints. The Type 7417 universal flow meter is described for use where a meter is desired with a uniform flow scale able to record temperature and pressure on the same chart with the flow. Write to Foxboro Co., Foxboro, Mass., for a free copy of this Bulletin No. D.M.F. 726.

Temperature Control. — Thermostat for temperature control in industrial or domestic installations, by Julien P. Friez & Sons, Inc., Baltimore, Md.

Less Oil—Less Often—a well-illustrated booklet which describes E. P.-treated, high-film-strength lubricants, known as Houghton's Sta-Put Series, grouped and graded according to industrial machinery applications. It may be had by writing E. F. Houghton & Co., 240 W. Somerset St., Philadelphia, Pa.

Neoprene vs. Rubber—Gives results of comparative tests of Neoprene and rubber for absorption of shock and vibration. These cover compression, set and recovery. E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

Coal and Ash Handling Equipment

Pulverized Coal Sampler.—Construction and method of operation of the Thorsten sampler are given in a 4-p. bulletin of The Thorsten Sampler Co., 5 Olympia Place, Pittsburgh, Pa.

Pumps

Thrustfree Multi-Stage Centrifugal Pumps—This 4-page catalog describes the Pennsylvania Principle of effecting nonleakage Dynamic Hydraulic Balance. Pennsylvania Pump and Compressor Co., Easton, Pa.

Type DC Close Coupled Centrifugal Pumps is the topic of discussion in 16-page bulletin 805. It includes the features of the design, details of construction and data for determining pump sizes. It is issued by Dayton-Dowd Co., Quincy, Ill.

Diesels and Gas Engines

Diesels in the Tropics—In the November issue of Baldwin-Southwark is an interesting account of the use of Diesels for power generation and pumping oil in Venezuela, and of furnishing of water, light and refrigeration in the jungle. Other articles treat of Sponge Iron, Testing Machines, and rubber lined bearings. Baldwin-Southwark Corp., Paschall Station, Philadelphia, Pa.

Heating, Ventilation and Air Conditioning, Building Materials, Fans and Blowers

Heat Control—In a 48-p. booklet is dramatized the story of the development of control of heat, covering the history of heat, its sources and measurement, what heat is and its use in industry, methods of heat conservation, materials used and the economics of their use. An interesting and well illustrated treatment of the subject. Copies of "Heat" may be had from Johns-Manville, 22 East 40th St., New York, N. Y.

Norblo High Speed Low Power Exhaust Fans is the title of bulletin 1002-3 which discusses the product in regard to construction, characteristics and specifications. This bulletin is issued by the Northern Blower Co., 6409 Barberton Ave., Cleveland, O.

Clear Windows.—To prevent condensation on windows in cold weather, the Windowstat, placed at the window, cuts down humidification of the air until moisture at the window is reduced. A 4-p. bulletin describes construction and operation. Julien P. Friez & Sons, Inc., Baltimore, Md.

Steam Specialties, Welding Equipment

Separators and Exhaust Heads—the subject of Bulletin 11 which gives a comprehensive discussion of steam, oil and air separators as well as the discussion of exhaust heads. Wright-Austin Co., 315 W. Woodbridge St., Detroit, Mich.

Arc Welding.—News about the contest for prizes offered by The James F. Lincoln Arc Welding Foundation with hints to authors regarding data to be included in papers submitted, answers to questions about the award and information in regard to prizes and classifications. Opportunity is offered for self-improvement and profitable use of spare time. The James F. Lincoln Arc Welding Foundation, Box 5728, Cleveland, Ohio.

Welded Construction — Methods of changing design of machines and structures to employ welded construction are discussed and illustrated in a 32-p. bulletin issued by The Lincoln Electric Co., 12818 Coit Road, Cleveland, Ohio.

Tools and Maintenance, Iron and Steel

Precision Lathe—A 9-in. lathe for speeds 40 to 1200 r.p.m. to cut right or left-hand threads 4 to 112 per in., also pipe threads, with lengths between centers of 17, 23, 29 or 35 in. and in floor or bench models is described in catalog No. 46 of South Bend Lathe Works, So. Bend, Ind.

Wrought Iron Uses—In this 32-p. booklet are illustrated 101 uses for wrought iron covering ships, locomotives, bridges, piping, water wheels, stacks, boilers, structural work, tanks and cars. It is issued by A. M. Byers Co., Pittsburgh, Pa.

Applications of Nickel Steels—Complete list of literature on production and industrial applications of nickel alloy steels, cast-irons and non-ferrous metals gives a brief outline of each book. It covers all kinds of alloys and all types of applications in machinery, tools and structures. Published by International Nickel Co., Inc., 67 Wall St., New York, N. Y.

Railroad Romance—A story in the current issue of The Power Specialist tells of recent development of the locomotive to its present streamlined form. Other articles describe water handling at the Calvert plant at Relay, Md., and construction of the ice floor of the rink at Cleveland, O. Copies may be had from Johns-Manville, 22 E. 40th St., New York, N. Y.

Power Plant Construction News

Calif., Avon—Pacific Gas & Electric Co., 445 Sutter Street, San Francisco, Calif., has plans under way for new steam-operated electric generating plant in vicinity of Avon, Contra Costa County. Cost estimated over $3,500,000, with transmission lines, power substations, switching stations and other structures. Tidewater Associated Oil Co., Los Angeles, Calif., is interested in project.

Calif., Oakland—Owens-Illinois Pacific Coast Co., 1855 Folsom Street, San Francisco, Calif., plans installation of electric power equipment in new glass bottle and container plant unit on Fruitvale Avenue, Oakland. Cost about $300,000. Work will begin early in 1938. J. H. Brunnier, Sharon Building, San Francisco, is consulting engineer. Company is a subsidiary of Owens-Illinois Glass Co., Toledo, Ohio.

Calif., Rialto—Union Ice Co., 354 Pine Street, San Francisco, Calif., plans new one and multi-story precooling plant at Rialto, San Bernardino County, where site is being secured. Cost about $75,000, with equipment.

Ill., Chicago—Continental Can Co., 100 East Forty-second Street, New York, N. Y., plans installation of electric power equipment in connection with new one-story mechanical plant at South Ashland Avenue and Thirty-seventh Streets, Chicago, where building, 100x400 ft., and site have been acquired for a stated consideration of $170,000, and will be remodeled and equipped.

Ill., Chicago—Illinois Zinc Co., 332 South Michigan Avenue, plans installation of electric power equipment in new mill for production of patented zinc alloys, on site to be selected soon in or near Chicago. It will comprise several one-story units. Entire project is reported to cost over $400,000.

Ill., Danville — Chicago & Eastern Illinois Railway Co., Danville, plans installation of electric power equipment in connection with rebuilding portion of local car and coach shops, recently destroyed by fire with loss reported at $100,000. General offices are at 332 South Michigan Avenue, Chicago, Ill.

Ind., Muncie — Board of Public Works is making surveys and estimates of cost for installation of new motor-driven pumping machinery and auxiliary equipment for increased capacity for municipal water system. Charles H. Hurd, Architects' and Builders' Building, Indianapolis, Ind., is consulting engineer.

Iowa, Maquoketa—Common Council will receive bids until January 6 for extensions and improvements in municipal electric power plant, including installation of a 875-hp. heavy-duty Diesel engine-generator unit, switchgear and auxiliary equipment.

Ky., Beattyville — Common Council has plans under way for new municipal light and power plant, for which a bond issue of $90,000 has been approved. Proposed to begin work early in 1938. It is understood that Diesel engine-generator units will be used.

Ky., Vanceburg — Board of Lewis County Commissioners, Vanceburg, has approved a bond issue of $148,000 for construction of new county-owned electric light and power plant. Plans will be prepared soon. Proposed to begin work early in 1938.

Md., Easton—Phillips Canning Co., Cambridge, Md., plans installation of power equipment in new two-story branch plant at Easton, to replace a unit recently destroyed by fire. Entire project will cost close to $60,000. Work will be placed under way soon.

Md., Hagerstown—City Council has rejected bids recently received for extensions and improvements in municipal electric power plant, including new building, and will ask new bids in near future. Entire project will cost about $200,000, including equipment. Wood & Kirkpatrick, Stock Exchange Building, Philadelphia, Pa., are consulting engineers.

Mass., Hopedale — Draper Corporation plans installation of electric power equipment in one-story addition to textile machinery-manufacturing plant, 35x 200 ft. Superstructure will begin soon. Entire project will cost over $50,000.

Mass., Peabody — City Council has plans maturing for extensions and improvements in municipal electric power station, with installation of additional equipment. Cost estimated close to $55,000. Arthur L. Nelson, Engineers, 31 St. James Avenue, Boston, Mass., are consulting engineers.

Mich., Mount Clemens—Health City Brewing Co., Inc., recently chartered with capital of $265,000, plans installation of power equipment in new local brewing plant, comprising former brewery of Mount Clemens Brewing Co., which will be remodeled and enlarged. Entire project will cost about $80,000. Walter Szynkarek is president.

Minn., Minneapolis—Northern States Power Co., Minneapolis, is arranging an appropriation of about $4,500,000 for expansion and improvements in steam-electric generating plants during 1938, including installation of new generating and other equipment for increased capacity and replacements.

Mo., Chillicothe — Board of Public Works has plans maturing for extensions and improvements in municipal electric power plant, with installation of new turbo-generator and auxiliary equipment, boilers, accessories, etc. Cost estimated close to $300,000. Henrici-Lowry Engineering Co., West Tenth Street Building, Kansas City, Mo., is consulting engineer.

Neb., Kearney—State Board of Control, State House, Lincoln, Neb., H. F. Peterson, secretary, has authorized plans for new steam power house at State Hospital at Kearney. Fund of $45,000 will be arranged. Proposed to begin work early next spring. John P. Helleberg, Kearney, is architect.

N. J., Harrison—American Oxygen Service Corporation, 600 Essex Street, manufacturer of industrial oxygen and oxygen equipment, plans installation of power equipment in new two-story plant addition, 100x110 ft., for which superstructure will begin soon. Cost close to $100,000.

N. J., Newark—Brass Yeast Corporation, 740 Frelinghuysen Avenue, Samuel Brass, president and treasurer, recently organized, plans installation of electric power equipment in new three-story yeast-manufacturing plant at location noted, totaling about 30,000 sq. ft. floor space. Entire project will cost close to $100,000.

N. Y., New York—Consolidated Edison Co. of New York, Inc., 4 Irving Place, is arranging fund of about $10,-000,000 through bond issue for extensions and improvements in steam-electric generating plants in 1938, including installation of new equipment for increased capacity and replacements.

Ohio, Dayton—Dayton Rubber Mfg. Co., West Riverview Avenue, plans installation of electric power equipment in new one-story addition to automobile tire-manufacturing plant. Entire project is reported to cost close to $60,000. Geyer & Neuffer, Ludlow Arcade Building, are architects.

Ore., Bonneville—Pennsylvania Salt Mfg. Co., Widener Building, Philadelphia, Pa., plans installation of electric power equipment in new plant near Bonneville, for production of sodium chlorate and kindred products. Electric power for operation will be secured from new hydroelectric generating plant of Federal Government at Bonneville, from which a transmission line will be built to plant site, where large power substation will be located. Entire project is reported to cost over $500,000.

Texas, Brenham — City Council has plans maturing for new municipal electric power plant and distributing system, with station installation to include three Diesel engine-generator units with gross capacity of about 1500-1600 hp., and auxiliary equipment. Fund of $310,000 has been arranged through Federal aid. Garrett Engineering Co., Houston, Texas, is consulting engineer.

Texas, Corpus Christi—Barnsdall Refining Corporation, Tulsa, Okla., plans installation of power equipment in new oil refining plant at Corpus Christi. A power house and pumping station will be built. Entire project will cost over $2,000,000.

Texas, Houston—Lone Star Creamery Co., 403 Washington Street, plans installation of electric power equipment in new milk products plant on local site at Leeland and Sampson Streets. Work is scheduled to begin soon. Cost over $250,000. J. A. Glover, 3415 Austin Street, Houston, is architect.

Va., South Norfolk—City Council has plans maturing for new municipal electric power plant, for which fund of $330,000 has been arranged through Federal aid. Proposed to begin work early in 1938. Wiley & Hughes, Peoples National Bank Building, Lynchburg, Va., are consulting engineers.

Va., Winchester—Winchester Woolen Co. plans new steam power house at local textile mill, with installation of boiler units and auxiliary equipment. Cost estimated close to $40,000, with equipment.

Wash., Spokane—International Harvester Co., 606 South Michigan Avenue, Chicago, Ill., Motor Truck Division, plans installation of electric power equipment in new one and two-story factory branch, 250x320 ft., fronting on line of Northern Pacific Railway, at Spokane. Entire project will cost over $200,000. Company engineering department is in charge.